

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
7 December 2006 (07.12.2006)

PCT

(10) International Publication Number
WO 2006/128286 A1

(51) International Patent Classification:

C10J 3/18 (2006.01) C10J 3/28 (2006.01)
C10J 3/16 (2006.01) C10J 3/86 (2006.01)
C10J 3/08 (2006.01)

(21) International Application Number:

PCT/CA2006/000882

(22) International Filing Date: 5 June 2006 (05.06.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/687,475 3 June 2005 (03.06.2005) US
60/797,959 5 May 2006 (05.05.2006) US

(71) Applicant (for all designated States except US): **PLASCO ENERGY GROUP INC.** [CA/CA]; 1145 Innovation Drive, Suite 100, Kanata, Ontario K2K 3G8 (CA).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **TSANGARIS, Andreas** [CA/CA]; 29 Confederation Private, Ottawa, Ontario K1V 9W6 (CA).

(74) Agent: **MBM & Co.**; P.O. Box 809, Station B, Ottawa, Ontario K1P 5P9 (CA).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

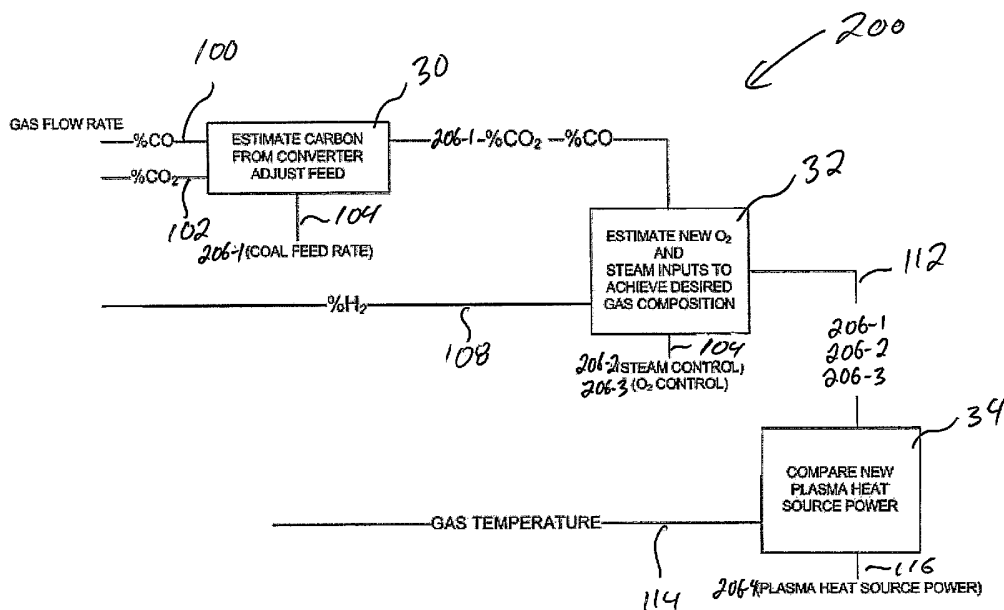
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: A SYSTEM FOR THE CONVERSION OF COAL TO A GAS OF A SPECIFIED COMPOSITION



(57) Abstract: The present invention provides a coal gasification system with an integrated control subsystem. The system generally comprises, in various combinations, a gasification reactor vessel (or converter) having one or more processing zones and one or more plasma heat sources, a solid residue handling subsystem, a gas quality conditioning subsystem, as well as an integrated control subsystem for managing the overall energetics of the conversion of coal to energy and maintaining all aspects of the gasification processes at an optimal set point. The gasification system may also optionally comprise a heat recovery subsystem and/or a product gas regulating subsystem.

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A SYSTEM FOR THE CONVERSION OF COAL TO A GAS OF A SPECIFIED COMPOSITION

FIELD OF THE INVENTION

This invention relates to the gasification of coal, and in particular to a process and apparatus for the conversion of coal to a gas having a specified composition.

BACKGROUND OF THE INVENTION

Coal of varying grades can be used as a primary feedstock for gasification. This includes low grade, high sulfur coal, which is not suitable for use in coal-fired power generators due to the production of emissions having high sulfur content. Waste coal particles and silt that remain after coal has been mined, sorted and washed is also useful for gasification. Coal can typically be gasified with oxygen and steam to produce so-called "synthesis gas" containing carbon monoxide, hydrogen, carbon dioxide, gaseous sulfur compounds and particulates. The gasification step is usually carried out at a temperature in the range of about 650°C to 1200°C, either at atmospheric pressure or, more commonly, at a high pressure of from about 20 to about 100 atmospheres.

There are several different types of coal, each displaying different properties resulting from geological history. The degree of coal development is referred to as a coal's "rank." Peat is the layer of vegetable material directly underlying the growing zone of a coal-forming environment. The vegetable material shows very little alteration and contains the roots of living plants. Lignite is geologically very young (less than 40,000 years). It can be soft, fibrous and contains large amounts of moisture (typically around 70%) and has a low energy content (8 – 10 MJ/kg). Sub-bituminous coal is a coal whose properties range from those of lignite to those of bituminous coal and are used primarily as fuel for steam-electric power generation. It may be dull, dark brown to black, soft and crumbly at the lower end of the range, to bright, jet-black, hard, and relatively strong at the upper end. Sub-bituminous coal contains 20 to 30 percent inherent moisture by weight. The heat content of sub-bituminous coal ranges from 20 to 28 MJ/kg on a moist, mineral-matter-free basis. Black coal ranges

from 65-105 million years old to up to 260 million years old. These are harder, shinier, less than 3% moisture and can have energy contents up to about 24 - 28MJ/kg. Anthracite contains virtually no moisture and very low volatile content, so it burns with little or no smoke. It can have energy contents up to about 32MJ/kg.

Synthesis gas is produced according to the Haber Bosch Process, which was developed in 1917. This process operates on the basic reforming reaction that reacts carbon e.g., coal with steam in a primary reaction to produce hydrogen and carbon monoxide. The hydrogen/carbon monoxide ratio of the synthesis gas varies widely depending on the nature of the coal feed. However, if one mole of methane was reformed with steam, it would produce a synthesis gas that is rich in hydrogen, e.g., three moles of hydrogen and one mole of carbon monoxide, i.e., a hydrogen/carbon monoxide ratio of 3/1. A competing secondary reaction known as the water gas shift reaction also takes place wherein carbon monoxide reacts with steam to form carbon dioxide and additional hydrogen. This water gas shift reaction is a secondary reaction since high temperature and lower pressure favor the primary reaction.

Because coal often contains sulfur compounds, attempts have been made to provide processes for the gasification of coal to produce a clean product fuel gas wherein the sulfur is removed from the product fuel gas prior to its use, e.g., in gas turbines to generate electricity. In addition, gases from the gasification zone may be purified to remove coal dust and fly ash and also many other impurities, e.g., vaporized ash, alkali, etc.

Plasma torch technology has been employed in coal gasification processes. Plasma torch technology was substantially advanced through the 1960's when new plasma generators were developed to simulate the very high temperature conditions experienced by space vehicles re-entering the Earth's atmosphere. Unlike a combustion burner flame, a plasma arc torch can be operated in the absence of oxygen. A plasma arc torch is created by the electrical dissociation and ionization of a working gas to establish high temperatures at the plasma arc centerline. Commercially-available plasma torches can develop suitably high temperatures for sustained periods at the point of application and are available in sizes from about 100 kW to over 6MW in output power.

Plasma is a high temperature luminous gas that is at least partially ionized, and is made up of gas atoms, gas ions, and electrons. Plasma can be produced with any gas in this manner. This gives excellent control over chemical reactions in the plasma as the gas might be neutral (for example, argon, helium, neon), reductive (for example, hydrogen, methane, ammonia, carbon monoxide), or oxidative (for example, oxygen, carbon dioxide). In the bulk phase, a plasma is electrically neutral. Thermal plasma can be created by passing a gas through an electric arc. The electric arc will rapidly heat the gas by resistive and radiative heating to a very high temperature within microseconds of passing through the arc. A typical plasma torch consists of an elongated tube through which the working gas is passed, with an electrode centered coaxially within the tube. In one type of such torch, a high direct current voltage is applied across the gap between the end of the center electrode as anode, and an external electrode as cathode. The current flowing through the gas in the gap between the anode and the cathode causes the formation of an arc of high temperature electromagnetic wave energy that is comprised of ionized gas molecules. Any gas or mixture of gases, including air, can be passed through the plasma torch.

There are also a number of patents relating to different technologies for the gasification of coal for the production of synthesis gases for use in various applications, including U.S. patent Nos. 4,141,694; 4,181,504; 4,208,191; 4,410,336; 4,472,172; 4,606,799; 5,331,906; 5,486,269, and 6,200,430.

The gas produced during the gasification of coal is usually very hot and dirty, and requires further treatment to convert it into a useable product. For example, wet scrubbers and dry filtration systems are often used to remove particulate matter and acid gases from the gas produced during gasification. A number of gasification systems have been developed which include systems to treat the gas produced during the gasification process.

The integration of a system for gasification of coal with advanced fuel cell technology requires a flexible, robust, and continuously operating reforming system that is applicable to various coal fuel qualities. Gasification systems incorporating plasma technology offer the potential to accept a wide variety of coal feeds, including coal

with high sulfur content. The incorporation of partial oxidation conditions within the reaction vessel is expected to provide the best gasification configuration, by optimizing the fuel gas composition, while minimizing energy requirements in the reaction vessel.

Syngas can be exploited for a variety of applications such as the conversion of the gas to energy in the form of electricity or chemical applications such as fuel cells or chemical feedstock. The equipment, which is used to directly convert syngas into electricity, currently comprises gas turbines and gas engines. These machines are designed to function within a very strict range of characteristics and are often very sensitive to changes in gas characteristics. In addition to affecting the efficiency of engine operation, a deviation in the gas characteristics may even have a negative effect on engine operation. For example, changes in the gas characteristics can affect the corrosion protection properties of the lubricating oil in an engine, as well it can affect emissions, efficiency, knock and combustion stability. Accordingly, these syngas-utilizing machines work most effectively when the characteristics of the gas are maintained within the specified limits.

This background information is provided for the purpose of making known information believed by the applicant to be of possible relevance to the present invention. No admission is necessarily intended, nor should be construed, that any of the preceding information constitutes prior art against the present invention.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a system for the conversion of coal to a gas of a specified composition, comprising: a gasification reaction vessel comprising one or more processing zones, one or more plasma heat sources; one or more coal input means for adding the coal to the gasification reaction vessel at an adjustable coal feed rate, one or more process additive input means for adding process additives to the gasification reaction vessel at an adjustable process additive feed rate, and one or more outlets for the output gas, a solid residue handling subsystem; a gas quality conditioning subsystem; an integrated control system comprising: system monitoring means for measuring one or more system parameters to generate data,

computing means for collecting and analyzing the data generated by the system monitoring means, and output means to send appropriate signals to effect change in one or more system regulators located throughout the system, wherein the control system monitors the one or more system parameters and sends signals to the appropriate system regulators to effect change in the one or more system regulators and thereby produce a product gas of a specified composition.

In one embodiment of the present invention, the gasification system may also optionally comprise a heat recovery subsystem and/or a product gas regulating subsystem

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features of the invention will become more apparent in the following detailed description in which reference is made to the appended drawings.

Figures 1 to 4 are schematic diagrams depicting a system for the conversion of coal to a gas of a specified composition in accordance with various exemplary embodiments of the present invention.

Figures 5 to 10 are schematic diagrams depicting various downstream applications for the system of Figures 1 to 4.

Figure 11 is a flow diagram depicting monitoring and regulating information flow between the system of Figures 1 to 10 and an integrated system control subsystem operatively coupled thereto.

Figure 12 is a schematic diagram depicting the integrated system control subsystem of Figure 11.

Figure 13 is a schematic diagram depicting exemplary monitoring and regulating signals respectively received from and transmitted to the system of Figures 1 to 10 by the integrated system control subsystem of Figure 11.

Figure 14 is a schematic diagram depicting exemplary monitoring and regulating access points of the integrated system control subsystem of Figure 11 to various devices, modules and subsystems of the system of Figures 1 to 10.

Figures 15 and 16 are schematic diagrams depicting an exemplary embodiment of the integrated system control subsystem of Figures 11 to 14 for controlling inputs to a plasma gasification vessel of the system of Figures 1 to 10.

Figures 17 to 19 are schematic diagrams depicting various entrained flow plasma gasification vessels for use with the systems of Figures 1 to 10.

Figures 20 and 21 are schematic diagrams depicting various fluidized flow plasma gasification vessels for use with the systems of Figures 1 to 10.

Figures 22 and 23 are schematic diagrams depicting moving bed flow plasma gasification vessels with grate options for use with the systems of Figures 1 to 10.

Figure 24 is a schematic diagram depicting an exemplary heat recovery subsystem for use with the systems of Figures 1 to 10.

Figure 25 is a schematic diagram depicting in greater detail, the gas-to-gas heat exchanger of Figure 24.

Figure 26 is a schematic diagram depicting in greater detail, the heat recovery steam generator of Figure 24.

Figure 27 is a schematic diagram depicting an optional steam/water treatment subsystem for treating a steam/water output from the Heat Recovery Steam Generation system of Figures 1 to 10, and particularly of Figure 2.

Figure 28 is a schematic diagram depicting various data inputs and outputs of a plasma gasification process simulation and system parameter optimization and modeling means, optionally used with the integrated control subsystem of Figures 11 to 16.

Figures 29 and 30 are schematic diagrams depicting further exemplary heat recovery subsystem for use with the systems of Figures 1 to 10.

DETAILED DESCRIPTION OF THE INVENTION

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs.

As used herein, the term “about” refers to a +/-10% variation from the nominal value. It is to be understood that such a variation is always included in any given value provided herein, whether or not it is specifically referred to.

For the purposes of the present invention, the term “syngas” or “synthesis gas” refers to the product of a gasification process, and may include carbon monoxide, hydrogen, and carbon dioxide, in addition to other gaseous components such as methane and water.

As used herein, the term “feedstocks” include, but are not limited to, any grade of coal (including low grade, high sulfur coal not suitable for use in coal-fired power generators).

The term “solid residue” means the solid by-product of coal gasification. Such a solid residue generally comprises inorganic, incombustible materials present in carbonaceous materials, such as silicon, aluminum, iron and calcium oxides. Examples of a solid residue include char, ash and slag.

“Slag” means a non-leachable, non-hazardous, glass-like material that consists of inorganic, incombustible material present in carbonaceous materials. In high temperature conditions (1300°C-1800°C) the mineral matter becomes molten. The molten slag forms a glassy substance upon quenching or cooling. This material is suitable for a number of commercial uses.

As used herein, the term "exchange-air" refers to air after it has been heated using sensible heat from the hot product gas using a gas-to-air heat exchanger according to the present invention.

Referring now to Figures 1 to 10, the present invention provides a coal gasification system, generally referred to using the numeral 10, with an integrated control subsystem 200, an exemplary embodiment of which is schematically illustrated in Figures 11 to 16. The system generally comprises, in various combinations, a gasification reactor vessel 14 (or converter) having one or more processing zones and one or more plasma heat sources, as in 15, a solid residue handling subsystem 16, a gas quality conditioning subsystem 20, as well as an integrated control subsystem 200 for managing the overall energetics of the conversion of coal to energy and maintaining all aspects of the gasification processes at an optimal set point (illustratively depicted at Figures 11 to 16). The gasification system may also optionally comprise a heat recovery subsystem 18 and/or a product gas regulating subsystem 22 (e.g., a homogenization chamber 25 as in the embodiment of Figure 1, a gas compressor 21 as in the embodiments of Figures 1 and 2, and/or a gas storage device 23 as in the embodiment of Figure 4, and the like).

The various embodiments of the coal gasification system 10, with an integrated control subsystem 200, convert coal to a gas of a specified composition. In particular, the present invention provides a system that allows for the efficient conversion of coal to a product gas having a composition appropriate for downstream applications. For example, if the product gas is intended for use in the generation of electricity through combustion in a gas turbine (i.e., ref. 24 in Figures 1 to 7) or use in a fuel cell application (i.e., ref. 26 in Figures 4 and 6 to 10), then it is desirable to obtain products that can be used as fuel in the respective energy generators. Alternatively, if the product gas is for use as a feedstock in further chemical processes (i.e., option 28 in Figure 4), the composition will be that most useful for a particular synthetic application.

With reference to Figures 11 to 16, the integrated control subsystem 200 comprises system monitoring means 202 for measuring one or more system parameters (e.g. gas

composition (%CO, %CO₂, %H₂, etc.), gas temperature, gas flow rate, etc.) and generating data from the measured system parameter values, as well as computing means 204 (schematically illustrated by the exemplary logic boxes 30, 32 and 34 in Figure 16), for collecting and analyzing the data generated from the system monitoring means 202 and outputting appropriate signals to one or more of the system regulators 206 (i.e., exemplary regulators 206-1, 206-2, 206-3 and 206-4 of Figures 15 and 16). The integrated control subsystem 200 manages the energetics of the conversion of coal to energy and maintains the processes at an optimum set point, by monitoring one or more system parameters via monitoring means 202, and sending signals to the appropriate system regulators 206 to make adjustments as required to maintain the reaction set point. Using the control subsystem 200 in accordance with the various embodiments of system 10 allows the production of a product gas having a specified flow and composition.

With reference to Figure 12, the integrated control subsystem 200, and particularly the computing means thereof 204, is generally comprised of one or more processors 208, one or more monitor inputs 210 for receiving current system parameter values from the various monitoring means 202, and one or more regulator outputs 212 for communicating new or updated system parameter values to the various regulating means 206. The computing means 204 may also comprise one or more local and/or remote storage devices 214 (e.g. ROM, RAM, removable media, local and/or network access media, etc.) for storing therein various predetermined and/or readjusted system parameters, set or preferred system operating ranges, system monitoring and control software, operational data, and the like. Optionally, the computing means 204 may also have access, either directly or via various data storage devices, to plasma gasification process simulation data and/or system parameter optimization and modeling means 216, an exemplary representation of which is provided in Figure 28. Also, the computing means 204 may be equipped with one or more graphical user interface and input peripherals 218 for providing managerial access to the control means 200 (system upgrades, maintenance, modification, adaptation to new system modules and/or equipment, etc.), as well as various output peripherals 220 for communicating data and information with external sources (e.g. modem, network connection, printer, etc.).

With reference to Figures 11 to 14, the control subsystem 200 of the present invention ensures that the gas flow and gas composition from the reaction vessel 14, and optionally throughout system 10, remains within predefined tolerances to result in the optimum production of the product gas and of system byproducts (commercial slag, gas recovery, steam generation, etc.), irrespective of the composition of different grades of coal or any natural variability in sources of the same type of coal. For example, there are many different grades of coal that are well known to those skilled in the art. Even within a single grade, coal is a complex material that may exhibit substantial variability. The control aspects of the present invention recognize and can make adjustments to compensate for such variability. The parameters of the product gas, such as temperature, flow rate and composition, are monitored, and the reactants are varied to maintain the parameters of the product gas within predetermined tolerances as defined by the end use of the synthesis gas.

The integrated control subsystem 200 of the present invention provides corrective feedback by which one or more of the flow rate, temperature and composition of the product gas are monitored and corrections made to one or more of the coal input rate, the oxygen input rate, the steam input rate and the amount of power supplied to the plasma heat sources. The adjustments are based on measured changes in the flow rate, temperature and/or composition of the product gas in order to ensure that these remain within acceptable ranges. In general, the ranges for the flow rate, temperature and/or composition of the product gas are selected to optimize the gas for a particular downstream application.

In one embodiment, the process of the present invention simultaneously uses the controllability of plasma heat to drive the gasification process, and to ensure that the gas flow and composition from the process remains within an acceptable range even if the composition of the coal exhibits natural variability. In another embodiment, the process allows for the total amount of carbon processed per unit time to be held as constant as possible, and utilizes the plasma heat to ensure that the total heat that enters and leaves the reaction vessel 14 per unit time is kept within process limits. The integrated control subsystem 200 may also be configured to monitor and/or regulate processes occurring via any one of the solid residue handling subsystem 16, the gas

quality conditioning subsystem 20, the heat recovery subsystem 18 and/or the product gas regulating subsystem 22, as schematically illustrated in Figure 14.

The gasification of coal takes place in the gasification reaction vessel 14 of the present invention, various exemplary embodiments of which are illustrated in Figures 17 to 23. The gasification reaction vessel 14, in addition to the one or more processing zones and the one or more plasma heat sources 15, also comprises means, as in 36, for inputting the coal into the gasification reaction vessel 14, as well as means, as in 38, for adding one or more process additives, such as steam or oxidant additives, as required for maintaining the gasification processes at an optimal set point. The gaseous products exit the gasification reaction vessel 14 via one or more output gas outlets, as in 40.

In one embodiment, the application of plasma heat, in conjunction with the input of process additives, such as steam and/or oxygen, helps in controlling the gas composition. The system 10 may also utilize plasma heat to provide the high temperature heat required to gasify the coal and/or to melt the by-product ash and convert it to a glass-like product with commercial value.

Various embodiments of the present coal gasification system 10 also provide means for managing the solid by-product of the gasification process. In particular, the invention provides a solid residue handling subsystem 16 for the conversion of the solid by-products, or residue, resulting from coal-to-energy conversion processes, into a vitrified, homogenous substance having low leachability. The solid by-products of the gasification process may take the form of char, ash, slag, or some combination thereof.

Illustratively, the solid residue handling subsystem 16 comprises a solid residue conditioning chamber 42, a plasma heating means 44, a slag output means 46, and a controlling means (which may be operatively linked to the overall control subsystem 200 of the system 10), whereby plasma heat is used to cause solids to melt, blend and chemically react forming a dense silicometallic vitreous material that, when poured out of the chamber 42, cools to a dense, non-leachable, silicometallic solid slag. In particular, the invention provides a solid residue conditioning chamber in which the

solid residue-to-slag conversion is optimized using the integrated control subsystem to control the plasma heat rate and solid residue input rate to promote full melting and homogenization.

Various embodiments of the present coal gasification system 10 also provide means for the recovery of heat from the hot product gas. This heat recovery subsystem 18 (exemplary embodiments of which are schematically illustrated in Figures 24 to 26, 29, 30) comprises means to transfer the hot product gases to one or more gas-to-air heat exchangers 48 whereby the hot product gas is used to heat air or other oxidant, such as oxygen or oxygen enriched air. The recovered heat, in the form of the heated air (or other oxidant), may then optionally be used to provide heat to the gasification process (see Figures 24 and 25), thereby reducing the amount of heat that must be provided by the one or more plasma heat sources to drive the gasification process. The recovered heat may also be used in industrial or residential heating applications.

Optionally, the heat recovery subsystem 18 additionally comprises one or more heat recovery steam generators (HRSG) 50 to generate steam which can, for example, be used as a process additive in the gasification reaction (see Figures 24 and 26), or to drive a steam turbine to generate electricity.

Also, as seen in Figures 29 and 30, the heat recovery subsystem 18 may also include additional heat recovery subsystems operatively extracting heat from various other system components and processes, such as via a plasma heat source cooling process 53, a slag cooling and handling process 55, GQCS cooling processes 61, and the like. The heat recovery system 18 may also comprise a feedback control system, which may be operatively coupled to the system's overall control subsystem 200, to optimize the energy transfer throughout the system 10 (e.g. see Figures 13 and 14).

Various embodiments of the present coal gasification system 10 also provide a gas quality conditioning subsystem (GQCS) 20, or other such gas quality conditioning means (an exemplary embodiment of which is illustrated in greater detail in Figure 1), to convert the product of the coal gasification process to an output gas of specified characteristics. The product gas is directed to the GQCS 20, where it is subjected to a particular sequence of processing steps to produce the output gas having the

characteristics required for downstream applications. The GQCS 20 comprises components that carry out processing steps that may include, for example, removal of particulate matter 54 (e.g. via a baghouse or the like), acid gases (e.g. H₂S removal means 56 and optional HCl removal means, such as an HCl scrubber 57, for possible small amounts of HCl), and/or heavy metals 58 from the synthesis gas, or adjusting the humidity and temperature of the gas as it passes through the system. The presence and sequence of processing steps is determined by the composition of the coal and the specified composition of output gas for downstream applications. The gas quality conditioning system 20 may also comprise an integrated control subsystem, which may be operatively linked to the overall integrated control subsystem 200 of the system 10, to optimize the GQCS process (e.g., see Figures 13 and 14).

Various embodiments of the present coal gasification system 10 also optionally provide a means, as in 22, for regulating the product gas, for example, by homogenizing the chemical composition of the product gas and adjusting other characteristics such as flow, pressure, and temperature of the product gas to meet downstream requirements. This product gas regulating subsystem 22 enables a continual and steady stream of gas of defined characteristics to be delivered to downstream applications, such as a gas turbine 24 or engine, a fuel cell application 26, and the like.

In particular, the product gas regulating subsystem 22 of the present invention provides a gas homogenization chamber 25 (Figure 1) or the like (compressor 21 of Figures 1, 2, gas storage device 23 of Figure 4, etc.) having dimensions that are designed to accommodate a gas residence time sufficient to attain a homogeneous gas of a consistent output composition. Other elements of the present product gas regulation system are designed to meet the gas performance requirements of the downstream application. The gas regulating system 22 may also comprise an integrated feedback control system, which may be operatively linked to the overall integrated control subsystem 200 of the system 10, to optimize the energetics and output of this process (e.g., see Figures 13 and 14)

With reference now to Figures 5 to 10, the person of skill in the art will understand that the present system 10 and integrated control subsystem 200, in their various

embodiments, may be used in a number of energy generation and conversion systems having numerous independent and/or combined downstream applications. For instance, in the exemplary embodiment of Figure 5, the system 10, an Integrated Gasification Combined Cycle (IGCC) system, may produce output energy (e.g. electricity) by providing both a syngas for use in one or more gas turbines 24, and steam, generated by cooling both the syngas and exhaust gas associated with the gas turbine 24 via one or more HRSG(s) 50, for use in one or more steam turbines 52.

In the exemplary embodiment of Figure 6, the system 10 combines an Integrated Gasification Combined Cycle (IGCC) system with a solid oxide fuel cell system 26S, the latter of which using a hydrogen-rich byproduct of the syngas to produce energy (e.g. electricity).

In the exemplary embodiment of Figure 7, the system 10 combines an Integrated Gasification Combined Cycle (IGCC) system with molten carbonate fuel cell system 26M, the latter of which, as in Figure 6, using a hydrogen-rich byproduct of the syngas to produce energy (e.g. electricity).

In the exemplary embodiment of Figure 8, the system 10 combines a solid oxide fuel cell system 26S, as in Figure 6, with one or more steam turbines 52 activated by steam generated by one or more HRSGs 50 recuperating heat from the syngas and the fuel cell output(s).

In the exemplary embodiment of Figure 9, a water-gas shift reactor 59 is added to the embodiment of Figure 8 to provide the hydrogen-rich syngas used in the solid oxide fuel cell system 26S.

In the exemplary embodiment of Figure 10, the solid oxide fuel cell system 26S of Figure 9 is replaced by a molten carbonate fuel cell system 26M.

As will be apparent to the person of skill in the art, the above exemplary embodiments of system 10 are not meant to be limiting, as one of skill in the art will understand that other such system configurations and combinations can be provided without departing from the general scope and spirit of the present disclosure.

Integrated Control Subsystem

As presented briefly above, the present system includes an integrated control subsystem 200. The control subsystem 200 comprises system monitoring means 202 for measuring one or more system parameters to generate data, computing means 204 (e.g., logic boxes 30, 32, 34 of Figure 16) for collecting and analyzing the data generated by the system monitoring means 202, and output means to send appropriate signals to effect change in one or more system regulators located throughout the system (i.e., regulators 206-1, 206-2, 206-3 and 206-4 of Figures 15 and 16). The integrated control subsystem 200 monitors the system parameters and sends signals to the appropriate system regulators 206 to make real time adjustments to various operating parameters and conditions as required in response to data obtained relating to measured parameters within the system 10. In one embodiment, the integrated control subsystem 200 provides a feedback control system to manage the energetics of the conversion of coal to energy and maintain a reaction set point, thereby allowing the gasification processes to be carried out under optimum reaction conditions to produce a gas having a specified composition.

The overall energetics of the conversion of coal to gas can be determined and achieved using the present gasification system. Some factors influencing the determination of the net overall energetics are: the BTU value and composition of the coal, the specified composition of the product gas, the degree of variation allowed for the product gas, and the cost of the inputs versus the value of the outputs. Ongoing adjustments to the reactants (for example, power for the plasma heat source(s) 15 and/or 44, process additives 38 such as oxygen and steam, percentage of sorbent in the coal) can be executed in a manner whereby the net overall energetics are assessed and optimized according to design specifications.

The control subsystem 200 of the present invention, therefore, provides a means for controlling in real time all aspects of the processes to ensure that the processes are carried out in an efficient manner, while managing the energetics and maintaining the reaction set point within certain tolerances. The real time controller is therefore

capable of simultaneously controlling all aspects of the process in an integrated manner.

The composition and flow of product gas from the reaction vessel 14 is controlled within predefined tolerances by controlling the reaction environment. The temperature is controlled at atmospheric pressure to ensure that the coal that is injected into the reaction vessel 14 encounters as stable an environment as possible. The control subsystem 200 of this invention provides means to control the amounts of coal, steam and oxygen that are fed into the reaction vessel 14.

Operating parameters which may be adjusted to maintain the reaction set point include coal feed rate, process additive feed rate, power to induction blowers to maintain a specified pressure, and power to and position of the plasma heat sources (e.g., plasma torches 15, 44). These control aspects will be discussed further having regard to each parameter.

With particular reference to Figures 13 and 14, and as briefly discussed above, the integrated control subsystem 200 may be integrated throughout the system 10 to monitor, via monitoring means 202, various system parameters, and implement, via regulating means 206, various modifications to these parameters to manage the energetics and maintain each aspect of the process within certain tolerances. These parameters, which will be discussed in greater detail below, may be derived from processes associated with one or more of the plasma gasification vessel 14, the solid residue handling subsystem 16, the plasma heat source(s) 15 and slag processing heat source(s) 44, the heat recovery subsystem 18 (e.g. gas-to-air heat exchanger 48 and/or HRSG 50) and process additive inputs 38 associated therewith, the primary and/or secondary feedstock inputs 36, 39 (e.g. carbon-rich additives), the GQCS 20, the homogenization chamber 25, and any other processing element or module of the system 10.

Furthermore, having access to these parameters and access, via the various local and/or remote storage devices 214 of computing means 204, to a number of predetermined and/or readjusted system parameters, system operating ranges, system monitoring and control software, operational data, and optionally plasma gasification

process simulation data and/or system parameter optimization and modeling means 216 (e.g. see Figure 28), the integrated control subsystem 200 may further interact with the system 10 in order to optimize system outputs.

System monitoring means

A number of operational parameters may be regularly or continuously monitored using the system monitoring means 202 of the control subsystem 200 to determine whether the system 10 is operating within the optimal set point. In one embodiment of the invention, means 202 are provided to monitor the parameters on a real time basis, thereby providing an instantaneous indicator of whether the system 10 is operating within the allowed/tolerated variability of the set point. Parameters that can be monitored include, but are not limited to, the chemical composition, flow rate and temperature of the product gas, the temperature at various points within the system 10, the pressure of the system, and various parameters relating to the plasma heat source(s) 15, 44 (i.e., power and/or position).

The parameters are monitored in real-time and the resulting data are used to determine if, for example, there needs to be more steam/oxygen (or other oxidants) injected into the system (e.g. via regulating means 206-2), if the coal input rate needs to be adjusted (e.g. via regulating means 206-1), or if the temperature or pressure in any of the components of the system requires adjustment.

System monitoring means may be located as required in any of the components of the GQCS 20, the heat recovery subsystem 18, the solid residue handling means 16, and the product gas handling subsystem 22, if such subsystems are present.

Composition of product gas

As discussed previously, if the product gas is intended for use in the generation of electricity, then it is desirable to obtain products that can be used as fuel to power energy generators. In this case, the optimal energetics are measured by the efficiency with which energy may be generated using the gases produced.

The main components of the output gas as it leaves the reaction vessel 14 are carbon monoxide, carbon dioxide, hydrogen, and steam, with lesser amounts of nitrogen. Much smaller amounts of methane, acetylene and hydrogen sulfide may also be present. The proportion of carbon monoxide or carbon dioxide in the output gas depends on the amount of oxygen that is fed into the reaction vessel 14. For example, carbon monoxide is produced when the flow of oxygen is controlled so as to preclude the stoichiometric conversion of carbon to carbon dioxide, and the process is so operated to produce mainly carbon monoxide.

The composition of the product synthesis gas may be optimized for a specific application (e.g., gas turbines 24 and/or fuel cell application 26 for electricity generation) by adjusting the balance between, for example, applied plasma heat 15, oxidant and/or steam process additives 38. Since addition of oxidant and/or steam process additives during the gasification process affects the conversion chemistry, it is desirable to provide means, as in monitoring means 202, for monitoring the syngas composition. The above-described inputs of the reactants are varied, e.g. via regulating means 206, to maintain the parameters of the synthesis gas within predetermined tolerances that are defined by the end use of the synthesis gas.

Monitoring of the product gas can be achieved using various monitoring means 202 such as a gas monitor and gas flow meter. The gas monitor may be used to determine the hydrogen, carbon monoxide and carbon dioxide content of the synthesis gas, the value of which is useable in various control steps, as illustratively depicted by the exemplary logic boxes 30 and 32 of Figure 16. Composition of the product gas is generally measured after the gas has been cooled and after it has undergone a conditioning step to remove particulate matter.

The product gas can be sampled and analyzed using methods well known to the skilled technician. One method that can be used to determine the chemical composition of the product gas is through gas chromatography (GC) analysis. Sample points for these analyses can be located throughout the system. In one embodiment, the gas composition is measured using a Fourier Transform Infrared (FTIR) Analyser, which measures the infrared spectrum of the gas.

In one embodiment, the parameters of the product gas, such as temperature, flow rate and composition, may be monitored via monitoring means 202 located at the axial outlet vent 40 of the reaction vessel 14. In another embodiment, sampling ports may also be installed at any location in the product gas handling system. As discussed previously, regulating means 206 are provided to vary the inputs of the reactants to maintain the parameters of the product gas within predetermined tolerances as defined by the end use of the product gas.

An aspect of this invention may consist in determining whether too much or too little oxygen is being added during the gasification process by determining the composition of the outlet stream and adjusting the process accordingly. In a preferred embodiment, an analyzer, sensor or other such monitoring means 202 in the carbon monoxide stream detects the presence and concentration of carbon dioxide or other suitable reference oxygen rich material.

It will be apparent that other techniques may be used to determine whether mostly carbon monoxide is being produced. In one alternative, the ratio of carbon dioxide to carbon monoxide may be determined. In another alternative, a sensor may be provided to determine the amount of oxygen and the amount of carbon downstream of the plasma generator, calculating the proportion of carbon monoxide and carbon dioxide and then making process adjustments accordingly. In one embodiment, the values of CO and H₂ are measured and compared to target values or ranges. In another embodiment, the product gas heating value is measured and compared to target values or ranges.

The person of skill in the art will understand that these and other such product gas composition measurements, which may be carried throughout a given embodiment of the system 10 via the above or other such monitoring means 202, may be used to monitor and adjust, via regulating means 206, the ongoing process to maximize process outputs and efficiencies, and should thus not be limited by the examples listed above and provided by the illustrative system and control subsystem configurations depicted in the appended Figures.

Temperature at various locations in system

In one embodiment of the invention, there is provided means, as in monitoring means **202**, to monitor the temperature at sites located throughout the system **10**, wherein such data are acquired on a continuous or intermittent basis. Monitoring means **202** for monitoring the temperature in the reaction vessel **14**, for example, may be located on the outside wall of the reaction vessel **14**, or inside the refractory at the top, middle and bottom of the reaction vessel **14**.

Monitoring means **202** for monitoring the temperature of the product gas may be located at the product gas exit **40**, as well as at various locations throughout the product gas conditioning system (e.g., within the GQCS **20**). A plurality of thermocouples can be used to monitor the temperature at critical points around the reaction vessel **14**.

If a system for recovering the sensible heat produced by the gasification process is employed (such as a heat exchanger or similar technology), as in **18**, a monitoring means **202** for monitoring the temperature at points in the heat recovery system (for example, at coolant fluid inlets and outlets) may also be incorporated. In one embodiment, a gas-to-air heat exchanger **48**, a heat recovery steam generator **50** (HRSG) or both are used to recover heat from the hot gases produced by the gasification process. In embodiments employing heat exchangers, the temperature transmitters are located to measure, for example, the temperatures of the product gas at the heat exchanger inlets and outlets. Temperature transmitters are also provided to measure the temperature of the coolant after heating in the heat exchanger.

These temperature measurements can be used to ensure that the temperature of the product gas as it enters a respective heat exchanger does not exceed the ideal operating temperature of that device. For example, in one embodiment, if the design temperature for a gas-to-air heat exchanger **48** is 1050°C, a temperature transmitter on the inlet gas stream to the heat exchanger **48** can be used to control both coolant air flow rates through the system and plasma heat power in order to maintain the optimum product gas temperature. In addition, measurement of the product gas exit

temperature may be useful to ensure that the optimum amount of sensible heat has been recovered from the product gas at all heat recovery stages.

A temperature transmitter installed on the air outlet stream to measure the temperature of the heated exchange-air ensures that the process is carried out under conditions that ensure the process air is heated to a temperature appropriate for use in the gasification process. In one embodiment, the coolant air outlet temperature is, for example, about 625°C, therefore a temperature transmitter installed on the air outlet stream will provide data that is used to determine whether adjustments to one or both of the air flow rates through the system and torch power in the plasma gasification vessel 14 (e.g., via regulating means 206-4 of Figures 15 and 16) should be made in order to maintain the optimum product gas input temperature, which in turn can be used to control the temperature of the coolant air.

According to one embodiment of the invention, the control strategy sets a fixed set point for the optimum coolant air output temperature, for example, about 600°C, as well as a fixed value for the HRSG gas exit temperature, for example, about 235°C. Therefore, according to this embodiment, when the product gas flow is reduced, the product gas temperature at the exit of the gas-to-air heat exchanger 48 gets cooler, resulting in decreased steam production because the HRSG gas exit temperature is also set to a fixed value.

The same concept applies when the airflow through the system is reduced. According to one embodiment of the present invention, the exit coolant air temperature remains fixed therefore the exit product gas temperature for the gas-to-air heat exchanger 48 is hotter, therefore producing more steam in the HRSG 50. However, when airflow through the system is reduced, product gas flow will consequently also reduce, so the increased inlet temperature to the HRSG 50 will only be momentarily high. For example, if airflow is reduced to 50%, the maximum inlet gas temperature that the HRSG 50 would momentarily see is approximately 800°C, which is within the temperature limits of the heat exchanger design.

In one embodiment of the invention, the monitoring means 202 for monitoring the temperature is provided by thermocouples installed at locations in the system 10 as

required. Such temperature measurements can then be used, as described above, by the integrated control subsystem 200, as illustratively depicted by the exemplary logic box 34 of Figure 16. The person skilled in the art will understand that other types of temperature measurements carried throughout a given embodiment of the system 10, via the above or other such monitoring means 202, may be used to monitor and adjust, via regulating means 206, the ongoing process to maximize process outputs and efficiencies, and should thus not be limited by the examples listed above and provided by the illustrative system and control means configurations depicted in the appended Figures.

Pressure of system

In one embodiment of the invention, there is provided monitoring means 202 to monitor the pressure within the reaction vessel 14, as well as throughout the entire system 10, wherein such data are acquired on a continuous or intermittent basis. In a further embodiment, these pressure monitoring means 202 comprises pressure sensors such as pressure transducers located, for example, on a vertical vessel wall. Data relating to the pressure of the system 10 is used by the control subsystem 200 to determine, on a real time basis, whether adjustments to parameters such as plasma heat source power or the rate of addition of coal are required (e.g., via regulating means 206-1 and 206-4 of Figures 15 and 16).

Variability in the amount of coal being gasified may lead to rapid gasification, resulting in significant changes in the pressure within the reaction vessel 14. For example, if an increased quantity of coal is introduced to the reaction vessel 14, it is likely that the pressure within the vessel 14 will increase sharply. It would be advantageous in such an instance to have monitoring means 202 to monitor the pressure on a continuous basis, thereby providing the data required to make adjustments in real time, via regulating means 206, to parameters (for example, the speed of the induction blower) to decrease the system pressure.

In a further embodiment, a continuous readout of differential pressures throughout the complete system 10 is provided, for example, via a number of pressure monitoring means 202. In this manner, the pressure drop across each individual component can

be monitored to rapidly pinpoint developing problems during processing. The person of skill in the art will understand that the above and other such system pressure monitoring and control means can be used throughout the various embodiments of system 10, via the above or other such monitoring means 202, to monitor and adjust, via regulating means 206, the ongoing process to maximize process outputs and efficiencies, and should thus not be limited by the examples listed above and provided by the illustrative system and control subsystem configurations depicted in the appended Figures.

Rate of gas flow

In one embodiment of the invention, there is provided monitoring means 202 to monitor the rate of product gas flow at sites located throughout the system 10, wherein such data are acquired on a continuous or intermittent basis.

The rate of gas flow through the different components of the system will affect the residence time of the gas in a particular component. If the flow rate of the gas through the reforming region of the gasification reaction vessel 14 is too fast, there may not be enough time for the gaseous components to reach equilibrium, resulting in a non-optimum gasification process. The person of skill in the art will understand that these and other such gas flow monitoring and control means can be used throughout the various embodiments of system 10, via the above or other such monitoring means 202, to monitor and adjust, via regulating means 206, the ongoing process to maximize process outputs and efficiencies via an integrated control subsystem, such as the exemplary control subsystem 200 depicted in Figures 11 to 16.

Computing Means

The control subsystem 200 comprises means for controlling the reaction conditions and to manage the chemistry and energetics of the conversion of the coal to the output gas. In addition, the control subsystem 200 can determine and maintain operating conditions to maintain ideal, optimal or not, gasification reaction conditions. The determination of ideal operating conditions depends on the overall energetics of the process, including factors such as the composition of the coal and the specified

composition of the product gases. The composition of the coal may be homogeneous or may fluctuate to certain degrees. When the composition of the coal varies, the certain system parameters may require continuous or regular adjustment, via regulating means 206, to maintain the ideal operating conditions.

The integrated control subsystem 200 can comprise a number of elements, each of which can be designed to perform a dedicated task, for example, control of the flow rate of one of the additives, control of the position or power output of one of the one or more plasma heat sources (e.g., 18, 44) of the gasification system, or control of the withdrawal of by-product. The control subsystem 200 can further comprise a processing system, as in processor(s) 208 of computing means 204.

In one embodiment, the processing system 204 can comprise a number of sub-processing systems. Each sub-processing system can be configured to implement a reaction model that can mimic at least one aspect of the plasma reforming reactions. Each reaction model has its own model input and model output parameters and can be used to calculate changes of the model output parameters as an effect of changes to the model input parameters. Each reaction model can be used to perform an assessment to help predict changes to the operating conditions of the gasification system before affecting any of the control elements of the system. Note that each reaction model can only be used within a predetermined range of operating conditions where the simulated predictions sufficiently accurately mimic processes of the (real) plasma reforming system.

The processing system can further be configured with partial models or a full model of the reaction processes of the gasification system. Partial models, topped by the full model, can be of enormous complexity and can be used to predict changes to an ever increasing number of operating conditions or can be used to expand the range of operating conditions within which the model is sufficiently accurate or valid. The higher the level of abstraction and completeness of the description of the reaction processes, the more powerful the predictions of the processing system. Increasing complexity of the full model, however, can affect the utility of the model for predicting certain effects on the operating conditions of the gasification system. Their

usefulness may be limited to predicting effects over short time periods or small parameter changes.

Figure 28 provides an exemplary embodiment of such a system model, which may be used in conjunction with the integrated control subsystem 200 to define various operational parameters, and predicted results based thereon, for use as starting points in implementing the various processes of system 10. In one embodiment, these and other such models are used occasionally or regularly to reevaluate and/or update various system operating ranges and/or parameters of the system 10 on an ongoing basis. In one embodiment, the NCR HYSYS simulation platform is used and can consider as inputs, any combination of input chemical composition, thermo-chemical characteristics, moisture content, feed rate, process additive(s), etc. The model may also take provide various optional interactive process optimizations to consider, for example, site and coal type specifics, maximization of energy recovery, minimization of emissions, minimization of capital and costs, etc. Ultimately, based on the selected model options, the model may then provide, for example, various operational characteristics, achievable throughputs, system design characteristics, product gas characteristics, emission levels, recoverable energy, recoverable byproducts and optimum low cost designs.

Each reaction model can be implemented exclusively in hardware or in any combination of software and hardware. A reaction model, as illustrated in Figure 28, can be described using any combination of an algorithm, a formula or a set of formulae that can be processed by the processing system. If the reaction model is exclusively implemented in hardware it can become an integral part of the processing system.

The processing system and any one of the sub-processing systems can comprise exclusively hardware or any combination of hardware and software. Any of the sub-processing systems can comprise any combination of one or more proportional (P), integral (I) or differential (D) controllers, for example, a P-controller, an I-controller, a PI-controller, a PD controller, a PID controller etc. It will be apparent to a person skilled in the art that the ideal choice of combinations of P, I, and D controllers will depend on the dynamics and delay time of the part of the reaction process of the

gasification system and the range of operating conditions that the combination is intended to control, and the dynamics and delay time of the combination controller.

Important aspects in the design of the combination controller can be short transient periods and little oscillation during transient times when adjusting a respective control variable or control parameter from an initial to a specified value. It will be apparent to a person skilled in the art that these combinations can be implemented in an analog hardwired form that can continuously monitor, via monitoring means 202, the value of a control variable or control parameter and compare it with a specified value to influence a respective control element to make an adequate adjustment, via regulating means 204, to reduce the difference between the observed and the specified value.

It will further be apparent to a person skilled in the art that the combinations can be implemented in a mixed digital hardware software environment. Relevant effects of the additionally discretionary sampling, data acquisition, and digital processing are well known to a person skilled in the art. P, I, D combination control can be implemented in feed forward and feedback control schemes.

Corrective control

In corrective, or feedback, control the value of a control parameter or control variable, monitored via an appropriate monitoring means 202, is compared to a specified value. A control signal is determined based on the deviation between the two values and provided to a control element in order to reduce the deviation. For example, when the output gas exceeds a predetermined H₂:CO ratio, a feedback control means, as in computing means 204, can determine an appropriate adjustment to one of the input variables, such as increasing the amount of additive oxygen to return the H₂:CO ratio to the specified value. The delay time to affect a change to a control parameter or control variable via an appropriate regulating means 206 is sometime called loop time. The loop time, for example, to adjust the power of the plasma heat source, the pressure in the system, or the oxygen or steam flow rate, can amount to 30 to 60 seconds.

In one embodiment, the product gas composition is the specified value used for comparison in the feedback control scheme described above, whereby fixed values (or ranges of values) of the amount of CO and H₂ in the product gas are specified. In another embodiment, the specified value is a fixed value (or range of values) for the product gas heating value.

Feedback control is required for all control variables and control parameters that require direct monitoring or where a model prediction is satisfactory. There are a number of control variables and control parameters of the gasification system 10 that lend themselves towards use in a feedback control scheme. Feedback schemes can be effectively implemented in aspects of the control subsystem 200 for those control variables or control parameters that can be directly sensed and controlled and whose control does not, for practical purposes, depend upon other control variables or control parameters.

Feed forward control

Feed forward control processes input parameters to influence, without monitoring, control variables and control parameters. The gasification system can use feed forward control for a number of control parameter such as the amount of power that is supplied to one of the one or more plasma heat sources (15, 44). The power output of the arcs of the plasma heat sources (15, 44) can be controlled in a variety of different ways, for example, by pulse modulating the electrical current that is supplied to the torch to maintain the arc, varying the distance between the electrodes, limiting the torch current, or affecting the composition, orientation or position of the plasma.

The rate of supply of additives that can be provided to the gasification reactor vessel 14 in a gaseous or liquid modification or in a pulverized form or that can be sprayed or otherwise injected via nozzles, for example can be controlled with certain control elements in a feed forward way. Effective control of an additive's temperature or pressure, however, may require monitoring and closed loop feed back control.

Fuzzy logic control and other types of control

Fuzzy logic control as well as other types of control can equally be used in feed forward and feedback control schemes. These types of control can substantially deviate from classical P, I, D combination control in the ways the plasma reforming reaction dynamics are modeled and simulated to predict how to change input variables or input parameters to affect a specified outcome. Fuzzy logic control usually only requires a vague or empirical description of the reaction dynamics (in general the system dynamics) or the operating conditions of the system. Aspects and implementation considerations of fuzzy logic and other types of control are well known to a person skilled in the art.

It will be understood that the foregoing embodiments of the invention are exemplary and can be varied in many ways. Such present or future variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be apparent to one skilled in the art are intended to be included within the scope of the following claims.

Gasification Reaction Vessels for Use with This System

With reference now to Figures 1 to 4, and Figures 17 to 23, the present coal gasification system 10 comprises a gasification reactor vessel 14 having one or more processing zones and one or more plasma heat sources, as in 15. The gasification reaction vessel 14 also comprises means, as in 36, for inputting the coal into the reaction vessel, as well as means, as in 38, for adding one or more process additives, such as steam or oxygen/oxidant additives, as required for maintaining the gasification processes at an optimal set point.

In one embodiment of the present invention, the one or more sources of plasma heat 15 assist in the coal-to-gas conversion process. In particular, the use of plasma heat sources 15, in conjunction with the input of steam and/or oxygen process additives 38, helps in controlling the gas composition. Plasma heat may also be used to ensure the complete conversion of the offgases produced by the gasification process into their constituent elements, allowing reformation of these constituent elements into the

product gas having a specified composition. The product gas may then exit the gasification reaction vessel 14 via one or more output gas outlets 40.

The gasification of coal (i.e., the complete conversion of the coal to a syngas) takes place in the gasification reaction vessel 14, and can proceed at high or low temperature, or at high or low pressure. A number of reactions take place in the process of converting coal to the syngas product. As the coal is gasified in the reaction vessel, the physical, chemical, and thermal processes required for the gasification may occur sequentially or simultaneously, depending on the reactor design.

In the gasification reaction vessel 14, the coal is subjected to heating, whereby the coal is dried to remove any residual moisture. As the temperature of the dried coal increases, pyrolysis takes place. During pyrolysis, volatile components are volatilized and the coal is thermally decomposed to release tars, phenols, and light volatile hydrocarbon gases while the coal is converted to char. Char comprises the residual solids consisting of organic and inorganic materials.

The resulting char may be further heated to ensure complete conversion to its gaseous constituents, leaving an ash by-product that is later converted to slag. In one embodiment, the gasification of coal takes place in the presence of a controlled amount of oxygen, to minimize the amount of combustion that can take place.

The combined products of the drying, volatilization and char-to-ash conversion steps provide an intermediate offgas product. This intermediate offgas gas may be subjected to further heating, typically by one or more plasma heat sources and in the presence of a controlled amount of steam, to complete the conversion of the coal to the syngas. This final step is also referred to as a reformation step.

The one or more plasma heat sources can be positioned to make all the reactions happen simultaneously, or can be positioned within the reaction vessel to make them happen sequentially. In either configuration, the temperature of the pyrolysis process is elevated due to inclusion of plasma heat sources in the reactor.

The gasification reaction is driven by heat, which can be fueled by adding electricity or fossil fuels (e.g., propane) to heat the reaction chamber or adding air as a reactant to drive the exothermic gasification reaction, which provides heat to the reaction. Some gasification processes also use indirect heating, avoiding combustion of the feed material in the gasification reactor and avoiding the dilution of the product gas with nitrogen and excess CO₂.

The gasification reaction vessel 14 can be based on one of a number of standard reactors known in the art. Examples of reaction vessels known in the art include, but are not limited to, entrained flow reactor vessels (Figures 17 to 19), moving bed reactors (Figures 22 and 23), fluidized bed reactors (Figures 20 and 21), and rotary kiln reactors (not shown), each of which is adapted to accept coal through a coal input means, as in 36. The coal is introduced through one or more inlets that are disposed to provide optimum exposure to heating for complete and efficient conversion of the coal to the product gas.

In one embodiment, the gasification reaction vessel 14 is designed to operate at or near atmospheric pressure. In another embodiment, the reaction vessel operates under pressurized conditions, whereby the gasification reaction is carried out at a pressure of between 2 to 10 atm. In yet another embodiment, the reaction vessel operates under high pressure whereby the gasification reaction is carried out at a pressure of up to 30 atm.

The gasification reaction vessel 14 can have a wide range of length-to-diameter ratios and can be oriented either vertically or horizontally. The gasification reaction vessel will have one or more gas outlet means 40, as well as means for removing solid residue (e.g., char, ash, slag or some combination thereof) 16, which is generally an outlet disposed somewhere along the bottom of the chamber (e.g., slag chamber 42) to enable the residue to be removed using gravity flow. In one embodiment, the gasification reaction vessel will use physical transfer means to remove the solid residue from the bottom of the vessel. For example, a hot screw (e.g., element 60 of Figure 20) may be used to convey the ash by-product into the slag processing chamber 42. Means for processing and handling slag will be discussed in more detail later. Note that the slag may also be processed in the same chamber in which the

gasification occurs (Figures 16 to 19), or in a separate chamber, as in slag chamber 42 of Figure 20.

According to the present invention, all of the steps for the conversion of coal to the syngas product take place in a single chambered reaction vessel.

The design of some gasification reaction vessels 14 is such that the process for converting the coal to a syngas may take place in a one-stage process, i.e., where all the steps in the conversion of coal to syngas take place generally in a single zone within the vessel. In one such embodiment, it is conceived that the one stage process takes place within a single zone in the reaction vessel 14, where all of the gasification steps take place in the same zone. In such a case, the product gas exiting the gasification reaction vessel 14 will be a syngas product.

The design of other gasification reaction vessels 14 is such that the coal to syngas conversion process takes place in more than one zone in the chamber, i.e., wherein the gasification and reformation steps are separated to some extent from each other and take place in different zones within the vessel.

In one embodiment of the invention, the conversion process takes place in two stages, first a coal to offgas stage, followed by a offgas to syngas (reformation) stage. In such a two stage process, it is conceived that at least two discrete zones (a first zone for the gasification step and a second zone for the reformation step) within a single chambered reaction vessel are required.

In a multi-region gasification reaction vessel, a first, or primary, zone is used to heat the coal to dry the coal (if residual moisture is present), extract the volatile constituents of the coal, and optionally convert the resulting char to a gaseous product and ash, thereby producing an offgas product, while a second zone is used to apply plasma heat to assure the complete conversion of the offgas into the syngas product. Where two or more distinct zones are used for the gasification of the coal and the conversion of offgas to syngas, the product gas exiting the final region of the gasification reaction vessel is a syngas.

In one embodiment, the heat required to drive the gasification of coal is provided by heated air. In such an embodiment, the gasification reaction vessel 14 comprises one or more heated air input means for the introduction of heated air to the gasification zone. The heated air input means includes exchange air inlets. These inlets are positioned within the reaction vessel to distribute the heated air throughout the reaction vessel to initiate and drive the conversion of the coal to a gaseous product.

With reference to Figures 22 to 23, the reaction vessels 14 depicted therein could be considered to encompass multiple zone vessels wherein the gasification processes takes place in a first zone 66 and the reformation processes occur within a second zone 68 of the vessel 14. Illustratively, the heat required to initiate the gasification process in the first zone is provided by plasma heat source 70 in the embodiment of Figure 23 and by an alternative heat source (e.g., heated air, etc.) in the embodiment of Figure 22. In both of these embodiments, a plasma heat source 72 is used in the second zone to upgrade the characteristics of the generated gas, in accordance with a specified output gas composition, for subsequent processing via the gas output 40.

Referring back to Figures 17 to 23, the person of skill in the art will understand that by moving the one or more plasma heat source 15, by adding other plasma heat sources, other sources of heat, and the like, the illustrated vessels 14 may be operated as single or multiple zone reaction vessels 14 without departing from the general scope and spirit of the present disclosure. Furthermore, it will be understood that the present coal gasification system 10 with integrated control subsystem 200 may be implemented with any of the above or other such gasification vessel configurations. In fact, by monitoring one or more direct or indirect process parameters relevant to the gasification and/or reformation processes implemented within a given type of reaction vessel, whether these processes take place in a single zone or multiple zones within a single chamber reaction vessel, the control subsystem 200 of the present system 10 may be used, via monitoring means 202, to monitor and adjust the ongoing processes to maximize, via regulating means 206, process outputs and efficiencies.

Furthermore, still referring to Figures 17 to 23, the gasification reaction vessel optionally comprises one or more process additive input means 38, which are provided for the addition of gases such as oxygen, air, oxygen-enriched air, steam or

other gas useful for the gasification process, into the gasification reaction vessel. The process additive input means can include air (or oxygen) input ports, steam input ports and/or sorbent ports. These ports are positioned within the reaction vessel 14 for the optimal distribution of process additives throughout the vessel. The addition of process additives will be discussed in greater detail later.

Also, in accordance with one embodiment of the present invention, the gasification reaction vessel wall is lined with refractory material. The refractory material can be one, or a combination of, conventional refractory materials known in the art which are suitable for use in a vessel for a high temperature (e.g., a temperature of about 1100°C to 1400°C) non-pressurized reaction. Examples of such refractory materials include, but are not limited to, high temperature fired ceramics (such as aluminum oxide, aluminum nitride, aluminum silicate, boron nitride, zirconium phosphate), glass ceramics, chromia refractories and high alumina refractories containing alumina, titania, and/or chromia.

As is understood by those of skill in the art, different regions of the gasification reaction vessel may be lined with different refractory materials, according to temperature and corrosion requirements of a particular region. For example, if slagging is present, it may be advantageous to use a non-wetting refractory material.

The person of skill in the art will further understand that, although the above description provides a number of examples of reaction vessel types, configurations and materials to be used therefor, other reaction vessel types, configurations and/or materials may be used without departing from the general scope and nature of the present disclosure.

Plasma Heating Means

Referring now to Figures 1 to 4 and 17 to 23, the system of the present invention employs one or more plasma heating means, as in 15, to ensure complete conversion of the offgas produced by the gasification process to a product gas having a specified composition. Plasma heating means as in 15 may also be optionally provided to heat the coal to drive the initial gasification process.

In one embodiment of the present invention, the one or more plasma heat sources 15 will be positioned to optimize the offgas conversion to specified product gas. The position of the one or more plasma heat sources is selected according to the design of the gasification system, for example, according to whether the system employs a one stage or two stage gasification process. For instance, in one embodiment that employs a two stage gasification process, the plasma heat source may be disposed in a position relative to the offgas inlet, and pointed in the direction of the offgas inlet. In another embodiment that employs a one stage gasification process, the one or more plasma heat sources 15 may extend towards the core of the gasification reaction vessel. In all cases, the position of the plasma heat sources is selected according to the requirements of the system, and for optimal conversion of the offgas to the specified product gas.

Where more than one plasma heat source is used, the position of the heat sources is also selected to ensure that there is no conflict between two or more heat sources, for example, that no heat source is subjected to direct heat from another or that there is no arcing from one plasma heat source to another.

In addition, the location of the one or more plasma heat sources is selected to avoid impacting the wall of the reaction vessel with the plasma plume, thereby avoiding the formation of "hot spots".

A variety of commercially available plasma heat sources that can develop suitably high temperatures for sustained periods at the point of application can be utilized in the system. In general, such plasma heat sources are available in sizes from about 100 kW to over 6 MW in output power. The plasma heat source, or torch, can employ one, or a combination, of suitable working gases. Examples of suitable working gases include, but are not limited to, air, argon, helium, neon, hydrogen, methane, ammonia, carbon monoxide, oxygen, nitrogen, and carbon dioxide. In one embodiment of the present invention, the plasma heating means is continuously operating so as to produce a temperature in excess of about 900 to about 1100°C as required for converting the offgas to the syngas product.

In this respect, a number of alternative plasma torch technologies are suitable for use in the present system. For example, it is understood that inductively coupled plasma torches (ICP) may be employed. It is also understood that transferred arc and non-transferred arc torches (both AC and DC), using appropriately selected electrode materials, may also be employed. Electrode materials may be selected from, but are not limited to, copper and its alloys, stainless steel and tungsten. Graphite torches may also be used. Selection of an appropriate plasma heating means is within the ordinary skills of a worker in the art.

In one embodiment, the plasma heat sources 15 are located adjacent to one or more air/oxygen and/or steam input ports 38 such that the air/oxygen and/or steam additives are injected into the path of the plasma discharge of the plasma heat source 15.

In a further embodiment, the plasma heat sources 15 may be movable, fixed or any combination thereof.

The process of the present invention uses the controllability of plasma heat to drive the conversion process and ensure that the gas flow and gas composition from the converter remain within predefined tight tolerances. Control of the plasma heat also assists in the efficient production of the product gases, irrespective of the composition of different coal sources or any natural variability in sources of the same type of coal.

In one embodiment, the control subsystem 200 comprises regulating means 206 to adjust the power of the plasma heat sources 15 to manage the net overall energetics of the reaction and maintain an optimal set point. In order to manage the energetics of the reaction, the power to the plasma heat source 15 may be adjusted to maintain a constant gasification system temperature despite any fluctuations in the composition of the coal and corresponding rates of feed of steam and air/oxidant.

The control subsystem 200 controls the power rating of the plasma heat source 15 relative to the measured parameters such as the rate at which coal and process additives are introduced into the gasification reaction vessel 14, as well as the temperature of the system as determined by temperature sensors, and other such monitoring means 202, located at strategic locations throughout the system 10. The

power rating of the plasma heat source 15 must be sufficient to compensate, for example, for loss of heat in the gasification reaction vessel 14 and to process the added coal efficiently.

For example, when the temperature of the reaction vessel 14 is too high, the control subsystem 200 may command a drop in the power rating of the plasma heat source 15 (e.g. via regulating means 206-4 of Figures 15 and 16); conversely, when the temperature of the melt is too low, the control subsystem 200 may command an increase in the power rating of the plasma heat source 15.

In one embodiment of the invention, the control subsystem 200 comprises regulating means 206 to control the position of the torch to ensure the maintenance of the optimal high temperature processing zone as well as to induce advantageous gas flow patterns around the entire reaction vessel 14.

One or more plasma heat sources, as in 44, are also optionally provided to ensure complete processing of the solid residue of the gasification process, as will be discussed later.

Coal input means

Still referring to Figures 1 to 4 and 17 to 23, the invention includes means, as in input means 36, for introducing coal to the gasification reaction vessel 14. The input means 36 are located to ensure that the coal is deposited at an appropriate location in the reaction vessel for optimum exposure to the gasifying heat source.

In one embodiment, the input means 36 is also provided with regulating means 206 for adjusting the feed rate to ensure that the coal is fed into the reaction vessel 14 at an optimum rate for maintaining the gasification reaction at an optimum set point.

In one embodiment, the control subsystem 200 comprises regulating means 206 to adjust the rate of coal input to manage the net overall energetics of the reaction. For example, the rate of coal addition to the gasification reaction vessel 14 can be adjusted to facilitate the efficient conversion of the coal into the product gases. The

rate of coal addition is selected to manage the overall energetics of the system according to the design specifications of the system 10, while maintaining the reaction set point within certain tolerances.

The selection of the input means 36 is made according to the requirements for feed dispersion, the operating pressure and the coal particle size. Input means 36 may include a screw auger, a pneumatic transport system, a plunger system, a ram system, a rotary valve system, or a top gravity feed system.

A conditioning process for preparing the coal prior to introduction to the reaction vessel may also be utilized. For example, the coal may be pulverized to a size that provides the necessary rapid reaction. Generally, the coal should be of a particle size of 0.75 inches or smaller. The coal may optionally be fed through a pre-heater where it is heated before being fed to the reaction vessel. Such pre-heated pulverized coal may be fed to the reaction vessel via heated coal line.

Process additive input means

Still referring to Figures 1 to 4 and 17 to 23, process additives may optionally be added to the reaction vessel 14 to facilitate efficient conversion of coal into product gases. The type and quantity of the process additives are very carefully selected to optimize coal conversion while maintaining adherence to regulatory authority emission limits and minimizing operating costs. Steam input ensures sufficient free oxygen and hydrogen to maximize the conversion of decomposed elements of the input waste into fuel gas and/or non-hazardous compounds. Air/oxidant input assists in processing chemistry balancing to maximize carbon conversion to a fuel gas (minimize free carbon) and to maintain the optimum processing temperatures while minimizing the relatively high cost plasma arc input heat. The quantity of both additives is established and very rigidly controlled as identified by the outputs for the waste being processed. The amount of oxidant injection is very carefully established to ensure a maximum trade-off for relatively high cost plasma arc input heat while ensuring the overall process does not approach any of the undesirable process characteristics associated with combustion, and while meeting and bettering the emission standards of the local area.

For those embodiments having the production of electrical energy as an objective, it is advantageous to produce gases having a high fuel value. The production of high quality fuel gases can be achieved by controlling reaction conditions, for example, by controlling the amount of process additives that are added at various steps in the conversion process.

The gasification reaction vessel 14, therefore, can include a plurality of process additive input ports 38, which may be provided for the addition of gases such as oxygen, air, oxygen-enriched air, steam or other gas useful for the gasification process. The process additive input means 38 can include air input ports and steam input ports. These ports are positioned within the reaction vessel for the optimal distribution of process additives through the reaction vessel 14. The steam input ports can be strategically located to direct steam into and around the high temperature processing zone and into the product gas mass prior to its exit from the reaction vessel. The air/oxidant input ports can be strategically located in and around the reaction vessel to ensure fill coverage of process additives into the processing zone.

In one embodiment, the control subsystem 200 comprises regulating means 206 to adjust the reactants to manage the net overall energetics of the reaction. For example, process additives may be added to the reaction vessel 14 to facilitate the efficient conversion of the coal into product gases. The type and quantity of the process additives are very carefully selected to manage the overall energetics of the system according to the design specifications of the system, while maintaining the reaction set point within certain tolerances. In another embodiment of the invention, the control subsystem 200 comprises regulating means 206 to control the addition of process additives to maintain an optimal reaction set point. In another embodiment of the control subsystem 200, regulating means 206 are provided to control the addition of two or more process additives to maintain the reaction set point. In yet another embodiment, regulating means 206 are provided to control the addition of three or more process additives to maintain the reaction set point.

In those embodiments comprising a one stage process, i.e., where the gasification and reformation steps both take place in a single chamber gasification reaction vessel 14,

it is advantageous to strategically locate additive input ports in and around the gasification reaction vessel 14 to ensure full coverage of process additives into the processing zone. In those embodiments wherein the process takes place in two stages, i.e., the gasification and reformation take place in discrete regions within the system, it may be advantageous to locate certain additive ports (for example, steam inputs) proximal to the region where reformation by the plasma torch, or other such plasma heat source 15, takes place.

In a further embodiment, the control subsystem 200 comprises regulating means 206 for adjusting the additive inputs based on data obtained from monitoring and analyzing the composition of the product gas, via various monitoring means 202 and computing means 204, whereby these data are used to estimate the composition of the feedstock. The product gas composition data may be obtained on a continuous or intermittent basis, thereby allowing the adjustments to additive inputs such as air, steam and carbon-rich additives to be made on a real-time basis (e.g. via regulating means 206-1, 206-2 and 206-3 of Figures 15 and 16). The product gas composition data may also be obtained on an intermittent basis.

The control subsystem 200 of the present invention includes a means, as in regulating means 206, for introducing the additives into the system when the concentration of certain product gases is not at an optimal level according to predetermined target levels, as monitored by various monitoring means 202. For example, in the event that a gas sensor detects too much carbon dioxide, the control subsystem 200 may reduce the delivery of oxidant into the converter to reduce the production of carbon dioxide (e.g. via regulating means 206-3 exemplified in Figures 15 and 16).

In one embodiment of the invention, the process is adjusted to produce mostly carbon monoxide, rather than carbon dioxide. In order to expedite the production of carbon monoxide in such an embodiment, the system will include a sensor, analyzer or other such monitoring means 202 for determining the amount of oxygen in the gaseous output stream. If the correct amount of oxygen from steam or air/oxidant inputs is used in the gasification process, the product gas will be mainly carbon monoxide. If there is too little oxygen, a considerable amount of elemental carbon or carbon black may form which will ultimately plug up equipment downstream from the reaction vessel. If there is too much oxygen in the system, too much carbon dioxide, which has

essentially no value, will be produced, which is undesirable if the objective of the process is to produce a fuel gas. In response to too much carbon dioxide in the system, any steam or air/oxidant being injected is reduced or eliminated by an appropriate signal from the control subsystem 200 (e.g. via regulating means 206-2 and/or 206-3 exemplified in Figures 15 and 16).

The conversion of coal into fuel gas within the gasification reaction vessel 14 is an endothermic reaction, i.e., energy needs to be provided to the reactants to enable them to reform into the specified fuel gas product. In one embodiment of the invention, a proportion of the energy required for the gasification process is provided by the oxidation of a portion of the initial gaseous products or coal within the reaction vessel 14.

Introduction of an oxidant into the reaction vessel 14 creates partial oxidation conditions within the reaction vessel 14. In partial oxidation, the carbon in the coal reacts with less than the stoichiometric amount of oxygen required to achieve complete oxidation. With the limited amount of oxygen available, solid carbon is therefore converted into carbon monoxide and small amounts of carbon dioxide, thereby providing carbon in a gaseous form.

Such oxidation also liberates thermal energy, thereby reducing the amount of energy that needs to be introduced into the gasification reaction vessel by the plasma heat. In turn, this increased thermal energy reduces the amount of electrical power that is consumed by the plasma heat source 15 to produce the specified reaction conditions within the reaction vessel 14. Thus, a greater proportion of the electricity produced by converting the fuel gas to electrical power in an electric power generating device (e.g., fuel cell application 26, gas turbine 24, etc.) can be provided to a user or exported as electrical power, because the plasma heat source 15 requires less electricity from such an electric power generating device in a system that employs the addition of an oxidant.

The use of oxidant inputs as a process additive therefore assists in maximizing the conversion of carbon to a fuel gas and to maintain the optimum processing temperatures as required while minimizing the relatively high cost plasma arc input

heat. The amount of oxidant injection is very carefully established to ensure maximum removal of carbon in gaseous form (CO and CO₂). Simultaneously, because the gasification of carbon reactions (combination with oxygen) are exothermic, substantial quantities of heat are produced. This minimizes the need for relatively high cost plasma arc input heat while ensuring the overall process does not approach any of the undesirable process characteristics associated with combustion. In one embodiment of the invention, the oxidant is air.

Although less fuel gas will be produced within the reaction vessel when partial oxidizing conditions exist (because some of the fuel gas or coal is oxidized to liberate thermal energy, and thus, less fuel gas is available to an electric power generating device), the reduction in electrical consumption by the plasma heat source offsets a possible loss in electrical energy production. In one embodiment of the invention, the control subsystem 200 comprises means to adjust the addition of process additives to maintain an optimal reaction set point (e.g. regulating means 206-2, 206-3 of Figures 15 and 16).

In one embodiment of the invention, the oxidant additive is selected from air, oxygen, oxygen-enriched air, steam or carbon dioxide. In those embodiments using carbon dioxide as an oxidizing process additive, the carbon dioxide may be recovered from the product gases and recycled into the process additive stream.

The selection of appropriate oxidizing additive is made according to the economic objectives of the conversion process. For example, if the economic objective is the generation of electricity, the oxidizing additive will be selected to provide the optimal output gas composition for a given energy generating technology. For those systems that employ a gas engine to generate energy from the product gases, a higher proportion of nitrogen may be acceptable in the product gas composition. In such systems, air will be an acceptable oxidant additive. For those systems, however, that employ a gas turbine 24 to generate energy, the product gases must undergo compression before use. In such embodiments, a higher proportion of nitrogen in the product gases will lead to an increased energetic cost associated with compressing the product gas, a proportion of which does not contribute to the production of energy.

Therefore, in certain embodiments, it is advantageous to use an oxidizer that contains a lower proportion of nitrogen, such as oxygen or oxygen-enriched air.

In those embodiments of the present invention that seek to maximize the production of electrical energy using the fuel gases produced by the gasification process, it is advantageous to minimize the oxidation of the fuel gas that takes place in the gasification reaction vessel. In order to offset any decrease in the production of fuel gas due to partial oxidation conditions, steam may also be used as the oxidizing additive. The use of steam input as a process additive ensures sufficient free oxygen and hydrogen to maximize the conversion of decomposed elements of the input coal into fuel gas and/or non-hazardous compounds.

For those embodiments having the production of electrical energy as an objective, it is advantageous to produce gases having a high fuel value. The use of steam as a process additive is known in the art. The gasification of coal in the presence of steam produces a syngas composed predominantly of hydrogen and carbon monoxide. Those of ordinary skill in the chemical arts will recognize that the relative proportions of hydrogen and carbon monoxide in the fuel gas product can be manipulated by introducing different amounts of process additives into the converter.

Steam input ports can be strategically located to direct steam into the high temperature processing zone and/or into the product gas mass prior to its exit from the reaction vessel 14.

In one embodiment, there is also provided means for adding sorbent to the gasification reaction vessel 14. As coal contains sulfur compounds, sorbents (such as granulated limestone or dolomite) are fed into the reaction vessel 14 along with the coal to adsorb sulfur released by the coal as it is gasified. The sorbent may be added by premixing with the coal before addition to the reaction vessel 14, or it may be added through a dedicated sorbent port. The integrated control subsystem 200 may be used, via appropriate monitoring means 202 and regulating means 206, to monitor and adjust sorbent use with the reaction vessel 14.

Solid Residue Handling Subsystem

Still referring to Figures 1 to 4 and 17 to 23, the present coal gasification system also provides means, for managing the solid by-product of the gasification process. In particular, the invention provides a solid residue handling subsystem 16 for the conversion of the solid by-products, or residue, resulting from coal-to-energy conversion processes, into a vitrified, homogenous substance having low leachability.

In particular, the invention provides a solid residue handling subsystem 16 in which the solid residue-to-slag conversion is optimized by controlling the plasma heat rate and solid residue input rate to promote full melting and homogenization. In one embodiment, the solid residue handling subsystem comprises a solid residue conditioning chamber 42 (or slag chamber) having a solid residue inlet, a plasma heating means, a slag outlet, optionally one or more ports, and a downstream cooling means for cooling and solidifying the slag into its final form. The integrated control subsystem 200 of the present invention also comprises regulating means 206 to regulate the efficient conversion of the solid residue into slag by providing monitoring means 202 to monitor temperature and pressure throughout the solid residue handling subsystem 16, as well as means to control such operational parameters as the power to the plasma heat source 44 and solid residue input rate.

The solid residue handling subsystem 16 of the present invention is adaptable to treat a solid residue stream coming out of any process that converts the coal into different forms of energy. This solid residue is typically in a granular state and may come from one or more sources such as the gasification reaction vessel 14 and optionally the gas quality conditioning subsystem 20. In all cases, the solid residue is heated to a temperature required to convert the solids into a vitrified, homogeneous substance that exhibits extremely low leachability when allowed to cool and solidify.

The solid residue handling subsystem 16 therefore ensures that the solid residue is brought up to an adequate temperature to melt and homogenize the solid residue. The solid residue handling subsystem 16 also promotes the capture of polluting solids (i.e., heavy metals) in the slag, as well as the formation of a clean, homogeneous (and potentially commercially valuable) slag product.

In order to ensure complete processing of the solid residue, the solid residue handling subsystem 16 is designed to provide sufficient residence time in the slag chamber 42. In one embodiment, the system 16 provides a residence time of at least 10 minutes. In another embodiment, the solid residue handling subsystem 16 provides a residence time of up to 1 hour. In yet another embodiment, the solid residue handling subsystem 16 provides a residence time of up to 2 hours.

The solid residue, which may take the form of char, ash, slag, or some combination thereof, will be removed, continuously or intermittently, from one or more upstream processes through appropriately adapted outlets and conveyance means as would be known to the skilled worker, according to the requirements of the system and the type of by-product being removed. In one embodiment, the solid residue is pushed into the slag chamber 42 through a system of hoppers and conveying screws.

The solid residue may be added in a continuous manner, for example, by using a rotating screw or auger mechanism. For example, in the embodiment of Figure 20, a screw conveyor 60 is employed to convey ash to a slag chamber 42.

Alternatively, the solid residue can be added in a discontinuous fashion. In one embodiment of the invention, the solid residue input means, attached to the solid residue conditioning chamber, may consist of a system of conveying rams. In such an embodiment, limit switches are employed to control the length of the ram stroke so that the amount of material fed into the vessel with each stroke can be controlled.

The solid residue input means will further include a control means such that the input rate of the solid residue can be controlled to ensure optimal melting and homogenization of the solid residue material.

In one embodiment, a plasma heat source 44, is employed to heat and melt the ash into slag. The molten slag, at a temperature of, for example, about 1300°C to about 1700°C, may be periodically or continuously exhausted from the slag chamber 42 and is thereafter cooled to form a solid slag material. Such slag material may be intended for landfill disposal. Alternatively, the molten slag can be poured into containers to

form ingots, bricks tiles or similar construction material. The solid product may further be broken into aggregates for conventional uses.

The solid residue handling subsystem 16, therefore, includes a slag output means through which molten slag is exhausted from the slag chamber 42. The output means may comprise a slag exit port 46, which is typically located at or near the bottom of the chamber 42 to facilitate the natural flow of the molten slag pool out of the chamber. The rate at which the molten slag flows out of the slag chamber may be controlled in a variety of ways that would be apparent to a person skilled in the art. For example, in one embodiment, the temperature differential between the point closest to the plasma heating means and the exit point may be adjusted to control the re-solidification time of the molten slag, e.g., through adjustments in the volume of solid residue material allowed to pool in the chamber.

The slag output means may further be adapted to minimize heating requirements by keeping the slag chamber 42 sealed. In one embodiment, the output means comprises a pour spout or S-trap.

As discussed previously, it may also be advantageous to aim the plume of one or more of the plasma heat sources 44 towards the slag pool at, or around, the slag exit port 46 to maintain the temperature of the molten slag and ensure that the slag exit port 46 remains open through the complete slag extraction period. This practice will also aid in maintaining the slag as homogeneous as possible to guard against the possibility that some incompletely-processed material may inadvertently make its way out of the solid residue handling subsystem 16 during slag extraction.

The molten slag can be extracted from the solid residue handling subsystem in a number of different ways as are understood by those of skill in the art. For example, the slag can be extracted by a batch pour at the end of a processing period, or a continuous pour throughout the full duration of processing. The slag from either pour method can be poured into a water bath, where the water acts as a seal between the external environment and the gasification system. The slag can also be dropped into carts for removal, into a bed of silica sand or into moulds.

The walls of the slag chamber 42 are lined with a refractory material that can be one, or a combination of, conventional refractory materials known in the art which are suitable for use in a chamber for extremely high temperature (e.g., a temperature of about 1300°C to 1800°C) non-pressurized reactions. Examples of such refractory materials include, but are not limited to, chromia refractories and high alumina refractories containing alumina, titania, and/or chromia. Selection of an appropriate material for lining the slag chamber is made according to their chemical composition, as well as their ability to resist the corrosive nature of the slag, by virtue of their highly dense (low porosity) microstructures. Corrosion rates can be decreased with lower temperatures or reduced heavy metal contamination. It is advantageous to select a non-wetting refractory material where slagging is present.

A solid residue conditioning chamber is designed for highly efficient heat transfer between the plasma gases and the solid residue in melting and homogenizing the solid residue. Thus, factors such as efficient heat transfer, adequate heat temperatures, residence time, molten slag flow, input solid residue volume and composition, etc. are taken into account when designing the solid residue conditioning chamber.

As discussed above, the physical design characteristics of the solid residue conditioning chamber are determined by a number of factors. These factors include, for example, the composition and volume of the solid residue to be processed. The solid residue that enters the chamber may be collected from more than one source simultaneously. Accordingly, the internal configuration and size of the solid residue conditioning chamber are dictated by the operational characteristics of the input solid residue to be processed.

Another factor to consider in the design of the solid residue conditioning chamber is the residence time required to ensure that the solid residue is brought up to an adequate temperature to melt and homogenize the solid residue.

The type of plasma heating means used, as well as the position and orientation, of the plasma heating means is an additional factor to be considered in the design of the solid residue conditioning chamber. The plasma heating means must meet the required temperature for heating the solid residue to required levels to melt and

homogenize the solid residue while allowing the resulting molten solid residue to flow out of the chamber.

The control subsystem 200 of the present invention regulates the efficient conversion of solid residue into slag by providing monitoring means 202 to monitor the temperature and optionally pressure at sites located throughout the solid residue handling subsystem 16, wherein such data are acquired on a continuous or intermittent basis. Monitoring means 202 for monitoring the temperature in the chamber, for example, may be located on the outside wall of the chamber, or inside the refractory at the top, middle and bottom of the chamber. The control subsystem 200 of the present invention also provides regulating means 206 for controlling operational parameters such as the power to the plasma heat source 44 and solid residue input rate.

For example, when the temperature of the melt is too high, the control subsystem 200 may command a drop in the power rating of the plasma heat source 44; conversely, when the temperature of the melt is too low, the control subsystem 200 may command an increase in the power rating of the plasma heat source 44.

In one embodiment, the solid residue handling subsystem 16 can also comprise a means for recovering heat (e.g. plasma heat source cooling means 53 and slag cooling means 55 of Figures 29, 30), which can reduce the amount of waste heat generated. Such heat recovery means can include, for example, heat exchangers. In such an embodiment, the control system can additionally control the operating conditions of the heat exchanger. The heat exchanger can have, for example, a number of temperature sensors, flow control elements, and other such monitoring and regulating means 202, 206.

The slag chamber may also include one or more ports to accommodate additional structural elements/instruments that may optionally be required. For example, a viewport that may include a plurality of closed circuit television ports to maintain operator full visibility of all aspects of processing, including monitoring of the slag exit port 46 for formation of blockages. In another embodiment, the slag chamber may include service ports to allow for entry into the chamber for scrubbing/cleaning,

maintenance, and repair. Such ports are known in the art and can include sealable port holes of various sizes.

Heat recovery Subsystem

Referring now to Figures 1 to 4, 24 to 26, 29, 30, the present coal gasification system 10 also provides means, as in 18, for the recovery of heat from the hot product gas. This heat recovery subsystem 18 comprises means to transfer the hot product gases to one or more gas-to-air heat exchangers 48 whereby the hot product gas is used to heat air. The recovered heat (in the form of the heated exchange-air) may then optionally be used to provide heat to the gasification process, as specifically illustrated in Figures 24 and 25, thereby reducing the amount of heat that must be provided by the one or more plasma heat sources 15 required to drive the gasification process. The recovered heat may also be used in industrial or residential heating applications.

In another embodiment, the gas-to-air heat exchanger 48 is employed to heat an oxidant, such as oxygen or oxygen-enriched air, which may then optionally be used to provide heat to the gasification process.

Different classes of gas-to-air heat exchangers 48 may be used in the present system, including shell and tube heat exchangers, both of straight, single-pass design and of U-tube, multiple pass design, as well as plate-type heat exchangers. The selection of appropriate heat exchangers is within the knowledge of the skilled worker.

Due to the significant difference in the ambient air input temperature and hot syngas, each tube in the gas-to-air heat exchanger 48 preferably has its individual expansion bellows to avoid tube rupture. Tube rupture presents a high hazard due to problems resulting from air entering gas mixture. Tube rupture may occur where a single tube becomes plugged and is therefore no longer expanding/contracting with the rest of the tube bundle.

In order to minimize the hazard potential from a tube leak, the system of the present invention further comprises one or more individual temperature transmitters associated with the product gas outlet of the gas-to-air heat exchanger 48. These

temperature transmitters are positioned to detect a temperature rise resulting from combustion in the event of having exchange-air leak into the syngas conduit. Detection of such a temperature rise will result in the automatic shut down of the induction air blowers which move the coolant air through the heat recovery system.

The gas-to-air heat exchanger 48 is designed to have product gas flow in the tubes rather than on the shell side. In one embodiment, the product gas flows vertically in a "once through" design, which minimizes areas where build up or erosion from particulate matter could occur. In an embodiment, the process air flows counter-currently on the shell side of the gas-to-air heat exchanger 48.

Optionally, the heat recovery subsystem additionally comprises one or more heat recovery steam generators, as in 50, to generate steam, which can be used as a process additive in the gasification reaction, as specifically illustrated in Figures 24 and 26, to drive a steam turbine 52, or to drive rotating process equipment, such as induction blowers. Heat from the product gas is used to heat water to generate steam using a heat exchanging means 50, such as a heat recovery steam generator (Figures 1, 3, 4), or a waste heat boiler (Figure 24). In one embodiment, the steam produced using heat from the product gas is superheated steam.

With specific reference to Figures 24 to 26, the relationship between a gas-to-air heat exchanger, as in 48, and a heat recovery steam generator, as in 50, is depicted in accordance with one embodiment of the invention. The exchange-steam can also be used as a process steam additive during the gasification process to ensure sufficient free oxygen and hydrogen to maximize the conversion of the coal into the syngas product.

Steam that is not used within the conversion process or to drive rotating process equipment, may be used for other commercial purposes, such as the production of electricity through the use of steam turbines, as in 52, or in local heating applications or it can be supplied to local industrial clients for their purposes, or it can be used for improving the extraction of oil from the tar sands.

In one embodiment, the heat recovery steam generator (or HRSG) 50 is located downstream from the gas-to-air heat exchanger 48. In another embodiment, the HRSG 50 employed in the present system is a shell and tube heat exchanger. The HRSG 50 is designed such that the syngas flows vertically through the tubes and water is boiled on the shell side.

The gas-to-air heat exchanger 48 and the HRSG 50 are designed with the understanding that some particulate matter will be present in the product gas. The particle size is typically between 0.5 to 350 micron. In one embodiment, the product gas velocities here are also maintained at a level high enough for self-cleaning of the tubes, while minimizing erosion.

If the temperature of the exiting product gas exceeds a predetermined limit, this may be an indication that the tubes are starting to plug, at which time the system should be shut down for maintenance. The heat exchangers are provided, as required, with ports for instrumentation, inspection and maintenance, as well as repair and/or cleaning of the conduits.

In an embodiment of the present invention, the system is run intermittently, i.e., subject to numerous start-up and shut down cycles as desired. Therefore, it is important that the equipment must be designed to withstand repeated thermal expansion and contraction.

In order to maximize the amount of sensible heat which can be recovered from the hot product gases, as well as the heated exchange-air and steam produced by the heat recovery system, the conduits between the components is optionally provided with a means for minimizing heat loss to the surrounding environment. Heat loss may be minimized, for example, through the use of an insulating barrier around the conduits, comprising insulating materials as are known in the art, or by designing the plant to minimize lengths of conduits.

With reference to Figures 2 and 27, in one embodiment of the present system 10, the steam recuperated from the outputs of the various steam turbines 52 (e.g. a steam turbine operating from steam generated by an HRSG 50 used to cool the syngas (line

86), a steam turbine operating from steam generated by an HRSG 50 used to cool a gas turbine/engine 24 and exhaust gas generated thereby (line 88), or any combination thereof), is cooled through an additional heat exchanger 90, which is fed by a cooling tower pump or the like. Upon exit from the exchanger 90, the cooled steam/water is pumped through a deaerator 92, fed by a soft water source with appropriate chemicals, to remove air and excess oxygen therefrom, to then be processed back to the boiler feed water of the exhaust gas HRSG 50 (line 94), the syngas HRSG 50 (line 96), etc.

As presented above, the present gasification system 10 also comprises an integrated control means 200 to optimize the transfer of energy throughout the system, thereby managing the energetics of the coal-to-energy conversion. The energetics of the coal-to-energy conversion can be optimized using the present system, since the recycling of the recovered sensible heat back to the gasification process reduces the amount of energy inputs required from external sources for the steps of drying and volatilizing the coal. The recovered sensible heat may also serve to minimize the amount of plasma heat required to achieve a specified quality of syngas. Thus, the present invention allows for the efficient gasification of coal, wherein the gasification heat source is optionally supplemented by air heated using sensible heat recovered from the product gas.

In order to optimize the efficiency of the present invention, the integrated control subsystem 200 also provides a means for controlling the conditions under which the present process is carried out, as well as the operating conditions of the system according to the present invention. These control means, which may be incorporated into the overall system control means 200, are provided to monitor one or more parameters, including, but not limited to, temperature and gas flow rates at specified locations throughout the system, and to adjust operating conditions accordingly, so as to maintain the system within defined parameters. Examples of operating conditions which may be adjusted by the control means, via regulating means 206, include one or more of the exchange-air flow rate, the product gas flow rate, the rate of coal input, the rate of input of process additives such as steam, and the power to the plasma heat sources 15, 44, etc.

For example, temperature transmitters (and other such monitoring means **202**) may be installed at specified locations throughout the system **10**. The temperature transmitters may be located to measure, for example, the temperatures of the product gas at the gas-to-air heat exchanger inlet and outlet, as well as the temperatures of the product gas at the HRSG inlet and outlet. Temperature transmitters may also be provided to measure the temperature of the process air after heating in the gas-to-air heat exchanger **48**, as well as to measure the temperature of the steam as it exits the HRSG **50**.

These temperature measurements can be used to ensure that the temperature of the syngas as it enters a respective heat exchanger does not exceed the ideal operating temperature of that device. For example, if the design temperature for the gas-to-air heat exchanger **48** is 1050°C, a temperature transmitter on the inlet gas stream to the heat exchanger can be used to control both exchange-air flow rates through the system and plasma heat power in order to maintain the optimum syngas temperature. In addition, measurement of the product gas exit temperature may be useful to ensure that the optimum amount of sensible heat has been recovered from the product gas at both heat recovery stages.

A temperature transmitter installed on the air outlet stream to measure the temperature of the heated exchange-air ensures that the process is carried out under conditions that ensure the process air is heated to a temperature appropriate for use in the gasification process. In one embodiment, the exchange-air outlet temperature is, for example, about 600°C, therefore a temperature transmitter installed on the air outlet stream will be used to control one or both of air flow rates through the system and plasma heat source power in the plasma reforming chamber in order to maintain the optimum syngas input temperature, which in turn can be used to control the temperature of the heated exchange-air.

According to one embodiment of the invention, the control strategy sets a fixed set point for the optimum heated exchange-air output temperature, for example, about 600°C, as well as a fixed value for the HRSG gas exit temperature, for example, about 235°C. Therefore, according to this embodiment, when the syngas flow is reduced, the exit gas temperature of the gas-to-air heat exchanger **48** gets cooler, resulting in

decreased steam production because the HRSG gas exit temperature is also set to a fixed value.

The same concept applies when the airflow through the system is reduced. According to an embodiment of the present invention, the exit exchange-air temperature remains fixed therefore the exit product gas temperature for the gas-to-air heat exchanger 48 is hotter, therefore producing more steam in the HRSG. However, when airflow through the system is reduced, product gas flow will consequently also reduce, so the increased inlet temperature to the HRSG 50 will only be momentarily high. For example, if airflow is reduced to 50%, the maximum inlet gas temperature that the HRSG 50 would momentarily see is approximately 800°C, which is within the temperature limits of the heat exchanger design.

In addition, regulating means 206 for controlling an automatic valve for venting process air to the atmosphere are also optionally provided and incorporated into the overall system control means 200, if more air than required for the gasification process is preheated. For example, in some instances it is necessary to heat more gas than required for the process due to equipment considerations (e.g., when starting a shutdown procedure). In such instances, the excess exchange-air can be vented as required.

The system may further comprise means for monitoring one or more of syngas composition, coal input rate, and process additive input rate (see Figures 15 and 16) in order to provide additional information as may be required to implement corrective procedures to maintain optimum processing conditions. Various such monitoring means 202 are known in the art and can be employed in the system of the present invention.

With reference to Figures 29 and 30, the heat recovery subsystem 18 described above may also provide for the cooling of the product gas as required for subsequent filtering and conditioning steps, namely with regards to the GQCS 20 (e.g. GQCS cooling means 61), as well as provide for the cooling of the plasma heat sources 15, 44 (e.g. source cooling means 53), slag handling and processing means (e.g. slag cooling means 55), etc.

Gas Quality Conditioning Subsystem

Referring now to Figures 1 to 4, the present coal gasification system 10 also provides a gas quality conditioning subsystem (GQCS) 20, or other such gas conditioning means, to convert the product of the coal gasification process to an output gas of specified characteristics.

Passage of the product gas through the GQCS 20 will ensure that the product gas is free of chemical and particulate contaminants, and therefore can be used in an energy generating system or in the manufacture of chemicals. This conditioning step can also be required in those embodiments of the invention that do not have the generation of energy or the manufacture of chemicals as an objective. For example, treatment of the product gas with the gas quality conditioning subsystem 20 can ensure that the product gas can be released through an exhaust mechanism while maintaining strict adherence to local emission standards.

In one embodiment, the objective for the gasification system 10 of the present invention is to produce a fuel gas with specific characteristics (i.e., composition, calorific heating value, purity and pressure) suitable for feeding into a gas turbine 24 for production of renewable electrical energy. Because the fuel is generated by the pyrolysis/gasification of coal through the process described herein, there will exist certain amounts of waste impurities, particulates and/or acid gases that are not suitable to the normal and safe operation of the gas turbines.

The product gas is directed to the GQCS 20, where it is subjected to a particular sequence of processing steps to produce the output gas having the characteristics required for downstream applications. As briefly presented above, the GQCS 20 comprises components that carry out processing steps that may include, but are not limited to, removal of particulate matter 54, acid gases (e.g. H₂S removal means 56 and optional HCl removal means, such as an HCl scrubber 57, for possible small amounts of HCl), and/or heavy metals 58 from the synthesis gas, or adjusting the humidity and temperature of the gas as it passes through the system. The presence and sequence of processing steps required is determined by the composition of the

synthesis gas and the specified composition of output gas for downstream applications. As presented above, the system 10 also comprises integrated control subsystem 200 to optimize the GQCS process.

In one embodiment, under vacuum extraction conditions of the induction fan of a gasification system, the hot product gas is continuously withdrawn from the gasification system through an exit gas outlet(s) 40 of the gasification system. A gas transfer means, such as a pipe or other conduit is used to transfer the gas from the gasification chamber 14 to the GQCS 20.

It is also contemplated that one or more GQCSs 20 may be used, such as a primary GQCS and a secondary GQCS. In this case, the secondary GQCS may be used to process material such as particulate matter and heavy metals that are removed from the gas stream in the primary GQCS. The output gas from the GQCS 20 can be stored in a gas storage tank 23 (Figure 4), fed through further processing means such as a homogenization chamber 25 (Figure 1) or alternatively, fed directly to the downstream application for which it was designed (i.e., Figures 2 and 3).

As discussed above, it is advantageous to provide means for cooling the hot product gas prior to such a conditioning step. This cooling step may be required to prevent damage to heat-sensitive components in the system. In one embodiment, cooling step is carried out by the heat recovery subsystem 18, whereby the heat recovered from the product gas may also be optionally recovered and recycled for use in the gasification process (see Figures 24 to 26).

In another embodiment, the gas from the gasification system is first cooled down by direct water evaporation in an evaporator such as quencher (not shown). In yet another embodiment, evaporative cooling towers (dry quench) may be used to cool the syngas that enters the GQCS 20 from the gasification system. The evaporative cooling tower is capable of cooling the temperature of the syngas from about 740°C to about 150-200°C. This process may be achieved using adiabatic saturation, which involves direct injection of water into the gas stream in a controlled manner. The evaporating cooling process is a dry quench process, and can be monitored to ensure

that the cooled gas is not wet, i.e., that the relative humidity of the cooled gas is still below 100% at the cooled temperature.

As mentioned above, the GQCS 20 may comprise means, as in 54, for removing particulate matter from the optionally cooled gas, as well as gaseous contaminants not compatible with downstream uses of the product gas, such as combustion in gas turbines 24 to produce electricity, or as a feedstock 28 in further chemical production processes. A particulate removal system 54 is incorporated to remove particulates that may be entrained in the fuel gas exiting the converter. Particulate removal systems 54 are widely available, and may include, for example, high-temperature (ceramic) filters, cyclone separators, a venturi scrubber, an electro filter, a candle filter, a crossflow filter, a granular filter, a water scrubber, a fabric baghouse filter (Figure 1) and the like, which are well known to practitioners of gas conditioning.

As is known in the art, particulates can be removed in a number of ways depending on particulate size. For example, coarse particles may be removed using a cyclone separator or filter. Smaller or finer particles may be removed using Wet ESP or Baghouse filters (Figure 1). In one embodiment, with as much as 10 g/Nm³ particulate loading it a physical barrier that will remove particulate matter with 99.9% efficiency may be required. Wet ESP is driven by an electrostatic field and may not be suitable for use with gas streams of high oxygen content without control mechanisms to trip the current if the oxygen content reaches a particular level.

In one embodiment, a first particle removal means is used to remove coarse particles, and a second particle removal means is used to remove smaller or finer particles. In one embodiment, the first particle removal means is a cyclone filter that can remove particles larger than 5-10 micron in size. In another embodiment, the second particle removal means is a baghouse filter.

Alternative embodiments may change the order of the various gas clean-up steps to use more efficiently the characteristics of alternative gas cleaning devices. However, depending on the specific particulate removal system employed, it may be desirable to cool the fuel gas exiting the reaction vessel 14 before it enters the particulate removal system as previously mentioned. The cooling of the fuel gas may be of particular

importance if a bag type filter is used for particulate removal, because bag type filters are often cellulose or organic polymer-based, and cannot withstand extremely high temperatures.

The dust is then collected and may be sent back to the gasification reaction vessel so that no hazardous, solid wastes are produced or generated in the gas conditioning system. Alternatively, the particulate may be directed to the slag reservoir (see Figure 1) to vitrify the scrubber solids into a non-leachable slag. In some cases, depending upon plant considerations and local regulations, solids from the gas clean-up system may be sent off-site for safe disposal.

There may also be provided means, as in 58, for removing mercury or other heavy metals from the product gas. For example, dry injection systems utilize a calculated amount of activated carbon, which is injected in the gas stream with enough residence time so that fine heavy metal particles and fumes can adsorb in the activated carbon surface. Heavy metals adsorbed on activated carbon can be captured in a baghouse filter. Alternatively, a wet ESP system may be used to capture the heavy metals adsorbed on activated carbon. In one embodiment of the invention, the heavy metal particles adsorbed on activated carbon are captured in a baghouse.

An acid scrubbing system is also an effective technique to capture heavy metals. This system requires the passage of the gas containing heavy metals to be passed through a packed column with low pH (normally 1-2) solution circulation. Heavy metals and heavy metal compounds react with acid to form their stable compounds. With this technique the heavy metal concentration in the circulation solution will increase and thus treatment of the resulting waste water may be required. In one embodiment, the GQCS 20 comprises an acid scrubbing system to remove heavy metals.

In one embodiment, the mercury removal means is provided by an activated carbon mercury polisher. An activated carbon filter bed can be used as the final polishing device for heavy metal. The product gas is passed through activated carbon bed that will adsorb heavy metal (mainly mercury) from the gas stream. Normally activated carbon filters are used to achieve above 99.8-99.9 % removal of mercury and used as a final polishing device with 7-8 inches of WC pressure drop.

An acid recovery subsystem 56 is coupled to the gas conditioning system 20, to recover sulfur or sulfuric acid (from high sulfur coal) and hydrochloric acid (from chlorinated hydrocarbons), which may have a marketable value. The acid removal system 56 may include scrubber systems, acid removal systems, and other conventional equipment related to sulfur and/or acid removal systems.

The following paragraph will be replaced with new data to be provided

The product gas produced in the coal gasification system will contain acid gases such as HCl and H₂S. The concentrations of these acid gases in the product gas range from about 0.05 to about 0.5% for HCl, and range from about 100 ppm to about 1000 ppm for H₂S. In one embodiment, the expected concentration of HCl is about 0.178 % and H₂S is about 666 ppm (0.07%). The emission limit for HCl is about 5 ppm while for SO₂ it is about 21 ppm.

Acid gas removal can be achieved by dry scrubbing or wet scrubbing. The main components of dry scrubbing are a spray dry absorber and soda ash or lime powder injection before baghouse filtration. Normally with dry scrubbing it is difficult to achieve more than 99% acid removal efficiency.

If the amount of chlorine is of economically significant size, the chlorine may be reclaimed. If chlorine is present in a nuisance amount, it is removed in any suitable manner (e.g. water or wet scrubber, activated bauxite adsorption, etc.). The gas may be treated to remove components such as chlorine in a gas/liquid scrubber-contactors. The greatest advantage of wet scrubbing is a large contact area for heat transfer and mass transfer with less pressure drop that will help sub cooling of the gas. Sodium hydroxide is the traditional alkaline solution used for wet scrubbing. In one embodiment, a packed column is used for scrubbing acid gas.

Sulfur compounds are among the first to recombine, either as elemental sulfur, as sulfur-oxygen compounds or sulfur-hydrogen compounds. In one embodiment where the amount of sulfur compounds justifies the cost, a sulfur recovery facility, as in 76, is positioned along the conduit at a location, adjacent the heat exchangers, where a temperature is reached where the sulfur compounds become stable. The type and size

of the sulfur recovery facility 76 depends on the expected amount of sulfur in the inlet stream.

If the anticipated amount of sulfur is fairly low, as expected in low sulfur grades of coal, an iron filing technique may be used to react sulfur with elemental iron to produce iron sulfide. This may be accomplished by circulating iron pellets between a compartment in the conduit and a recovery compartment.

For coal that contains a high amount of sulfur, a second-stage liquid washing process is used to remove sulfur compounds from the gas. Sulfur may be recovered by any suitable technique, depending on the amount of sulfur anticipated in the inlet stream. Further downstream, an amine scrubber removes hydrogen sulfide and carbon dioxide from the gas stream leaving a stream mainly comprising hydrogen, carbon monoxide and an inert gas. Such amine scrubbers are known in the art and generally comprise an amine process wherein an aqueous solution of monoethanolamine, diethanolamine, or methyldiethanolamine is used to remove H₂S from the processed gas. Other methods for recovering sulfur may include, for example, a Claus plant (Figure 1), a Resox reduction process, a cold plasma hydrogen sulfide dissociation process, and the like.

In addition, suitable methods for the removal of sulfur include, for example, wet absorption with NaOH or triazine, dry adsorption with Sulfatreat, biological processes such as Thiopaq, or selective oxidation, including liquid redox (Low CAT). In one embodiment, H₂S is removed from the synthetic gas using Thiopaq (see Figure 1). Thiopaq is a two step process in which sour gas is scrubbed with a mild alkaline solution (at 8.5 to 9 pH) and the sulfur subsequently recovered (HS⁻ is oxidized to elemental sulfur by a biological process). Other methods may include, but are not limited to, a moving bed zinc titanate or ferrite adsorption process, oxidation chemical reaction processes (e.g. Stretford and SulFerox), and a Selexol acid removal process, the latter of which generally involves the use of a physical solvent (e.g., polyethylene glycol dimethyl ether) at high pressures (e.g. 300-1000 psig).

Furthermore, dioxins may be formed at a temperature of 250 -350°C in the presence of carbon that will act as catalyst, although plasma gasification conditions are known to hinder their formation. For additional minimization of dioxin formation, quenching of synthesis gas is normally done in a quencher or spray dryer absorber to ensure fast quenching is done between the above temperature range. Activated carbon injection in the synthesis gas will absorb dioxin and furan on carbon surface followed by removal in baghouse filters.

Demisters or reheaters could also be incorporated for moisture removal and/or prevention of condensation. Heat exchangers can be included to reheat the fuel gas to the inlet temperature required by the downstream power generation equipment. A compressor can also optionally be included to compress the fuel gas to the inlet pressures required by downstream power generation equipment.

In yet another embodiment, a humidity control means can be part of the GQCS 20. The humidity control means functions to ensure that the humidity of the output gas is appropriate for the downstream application employed. For example, a humidity control means may include a chiller to cool the gas stream and thus condense some water out of the gas stream. This water can be removed by a gas/liquid separator. In one embodiment such treatment of the gas stream ensures that the gas stream exiting from the GQCS 20 has a humidity of about 80% at 26°C. The gas may then be stored (e.g., in gas storage device 23).

In another embodiment, the gas processing subsystem can include means for the recovery of carbon dioxide and/or means for recovery of ammonia. Suitable means are known in the art.

The product gas is also sampled for gas chromatography (GC) analyses to determine chemical composition. Sample points for these analyses are spread throughout the product gas handling/pollution abatement subsystem.

In one embodiment, the control subsystem 200 comprises means to adjust the operating conditions in the conversion system, including the operating conditions in

the GQCS 20, thereby managing the net overall energetics of the conversion process, and maintaining a set point for reaction conditions within a specified range of variability during the conversion of coal to a product gas having a specified chemical and physical composition. This system can be automated and applied to a variety of gasification systems.

The control subsystem 200 may provide the following functions. In one embodiment, the control subsystem 200 may sense decrease in efficiency or alternate functional deficiency in a process of the GQCS 20 and divert the gas stream to a backup process or backup conditioning system. In another embodiment, the control subsystem 200 may provide a means for fine-tuning the steps of the GQCS 20 and providing minimal drift from optimal conditions.

The control subsystem 200 of this invention can include monitoring means 202 for analyzing the chemical composition of the gas stream through the GQCS 20, the gas flow and thermal parameters of the process; and regulating means 206 to adjust the conditions within the GQCS 20 to optimize the efficiency of processing and the composition of the output gas. Ongoing adjustments to the reactants (for example, activated carbon injection with sufficient residence time, pH control for the acid gas scrubber) can be executed in a manner that enables this process to be conducted efficiently and optimized according to design specifications.

Subsystem for Regulating the Product Gas

The present coal gasification system also optionally provides a means, for regulating the product gas, for example, by homogenizing the chemical composition of the product gas and adjusting other characteristics such as flow, pressure, and temperature of the product gas to meet downstream requirements. This product gas regulating subsystem 22 enables a continual and steady stream of gas of defined characteristics to be delivered to downstream applications, such as a gas turbine 24 or engine.

As is understood by those skilled in the art, the gasification process may produce gases of fluctuating composition, temperature or flow rates. In order to minimize the fluctuations in the characteristics of the product gas, there may be provided a gas

regulation system 22 in the form of a capturing means useful for delivering to downstream equipment a product gas having consistent characteristics.

In one embodiment, the present invention provides a gas regulation system 22 that collects the gaseous products of the gasification process and attenuates fluctuations in the chemistry of the gas composition in a homogenization chamber 25, or the like. Other elements of the system optionally adjust characteristics of the gas such as flow, temperature and pressure to fall within ranges that are acceptable to the downstream applications. The system thereby regulates the characteristics of the product gas to produce a continual stream of gas with consistent characteristics for delivery to a downstream application, such as a gas engine or a gas turbine 24.

In particular, the optional product gas regulating subsystem 22 of the present invention provides a gas homogenization chamber 25 (Figure 1) or the like (e.g. the gas compressor 21 of Figures 1 and 2, the gas storage device 23 of Figure 4, etc.) having dimensions that are designed to accommodate a residence time sufficient to attain a homogeneous gas of a consistent output composition. Other elements of the present gas regulation system are designed to meet the gas performance requirements of the downstream application. The system also comprises a control subsystem 200 to optimize the energetics and output of the process.

The composition of the product gas entering the regulation system 22 of the present invention, is determined in the gasification process. Adjustments made during the gasification process permit the product gas to be optimized for a specific application (e.g., gas turbines 24 or fuel cell application 26 for electricity generation). Accordingly, the composition of the product gas can be tailored for particular energy generating technologies (for example, for specific gas engines or gas turbines 24) and, for best overall conversion efficiency, according to the different types of coal and process additives used, by adjusting the operational parameters of the gasification process.

The product gas leaving the gasification system may be within a defined range of a target composition, however, over time the product gas may fluctuate in its

characteristics due to variability in the gasification process such as coal composition and feed rate, as well as airflow and temperature fluctuations.

Similar to the control of the composition of the product gas, the flow rate and temperature of the product gas can be monitored, for example via monitoring means 202, and controlled in the gasification system, for example via regulating means 206, in order to maintain the parameters of the gas within predetermined tolerances defined by the end use. Irrespective of these controls, fluctuations in flow rate and temperature of the product gas, over time, will occur. In the case of flow rate, these fluctuations may occur on a second to second basis; and with temperature on a per minute basis.

Conversion of product gas to a gas having a specified composition that meets the requirements of the particular application equipment, can be effected in the regulation system of the present invention. The regulation system comprises one or more gas homogenization chambers 25 having a product gas inlet means, a regulated gas outlet means, and optionally an emergency exit port.

The product gas homogenization chamber 25 receives the product gas produced from a gasification system and encourages mixing of the product gas to attenuate any fluctuations in the chemical composition of the product gas in the homogenization chamber 25. Fluctuations in other gas characteristics, such as pressure, temperature and flow rate, will also be reduced during mixing of the product gas.

The dimensions of the chamber are designed according to the performance characteristics of the upstream gasification system and the requirements of the downstream machinery, with the objective of minimizing the size of the chamber as much as possible. The gas homogenization chamber 25 is designed to receive product gas from a gasification process and retain the gas for a certain residence time to allow for sufficient mixing of the gas in order to achieve a volume of gas with a consistent chemical composition.

The residence time is the amount of time that the product gas remains in the homogenization chamber 25 before being directed to the downstream equipment. The

residence time is proportional to the response time of the related gasification system to correct for variances in the fluctuations in the gasification reaction in order to achieve a gas composition that falls within accepted tolerance values. For example, the gas composition is retained in the homogenization chamber 25 long enough to determine whether it falls within the gas composition tolerance allowed for the particular downstream application as well as to make any adjustments to the gasification process to correct for the deviance.

Additionally, residence time of the product gas in the homogenization chamber 25 is determined by the amount of variance in the product gas characteristics. That is, the smaller the variance in product gas characteristics, the shorter the residence time required in the homogenization chamber 25 to correct for the variance.

The optional gas regulating subsystem 22 is designed to provide sufficient residence time in a homogenization chamber 25. In one embodiment, the gas regulating subsystem 22 provides a residence time of at least 1 second. In another embodiment, the gas regulating subsystem 22 provides a residence time no more than 2 seconds. In yet another embodiment, the gas regulating subsystem 22 provides a residence time of 2 to 10 seconds. In yet another embodiment, the gas regulating subsystem 22 provides a residence time of up to 30 second.

The regulated gas exiting the optional regulation system 22 of the present invention will have stabilized characteristics that meet the specifications of the downstream application. Typically, machine manufacturers will provide the requirements and tolerances allowed by the specific machinery and would be known to the person skilled in the art.

Use of the Gasification System / The Process

The system according to the present invention gasifies coal, using a process for gasification of the coal that generally comprises the steps of passing the coal into a gasification reaction vessel 14 where it is heated, dried and volatile components in the dried feedstock are volatilized. In one embodiment of the invention, heated air is used

to further drive the complete conversion of the resulting char to its gaseous constituents, leaving an ash by-product. The combined products of the drying, volatilization and combustion steps provide an offgas that is further subjected to the heat from a plasma heat source 15 to convert the offgas to a hot gaseous product comprising carbon monoxide, carbon dioxide, hydrogen and steam. Steam and/or air/oxidant process additives 38 may be optionally added at the gasification stage and/or the offgas conversion stage.

In one embodiment of the invention, the process further comprises the step of subjecting by-product ash to heating by means of a second plasma heat source 44 to form a slag product.

The process of the present invention further comprises the steps of passing the hot product gas through a heat exchanging subsystem 18, transferring heat from the hot gas to a coolant. In one embodiment, the coolant is air. In another embodiment, the coolant is an oxidant selected from oxygen or oxygen-enriched air.

The process of the present invention optionally comprises the steps of passing the cooled gas product into a second heat exchanger 18, transferring heat from the cooled gas to a coolant that is water to produce a further cooled gas product and steam.

The process of the present invention maximizes net conversion efficiency by offsetting the amount of electricity that has to be consumed, for example, to create the heat that drives the gasification process, to drive rotating machinery, and to power the plasma heat sources 15, 44. For applications having the objective of generating electricity, the efficiency is measured by comparing the energy consumed by the overall gasification process with the amount of energy generated using the product gas (for example, to power gas turbines 24 or in fuel cell technologies 26), and through the recovery of sensible heat to generate steam to power steam turbines 52.

The gasification process can further comprise a corrective (or feedback) control step of adjusting one or more of the coal input rate, the product gas flow rate, the air/oxidant and/or steam process additive input rate, the pressure of the system, and the amount of power supplied to the plasma heat sources based on measured changes

in the flow rate, temperature and/or composition of the product gas. The feedback control step thus allows the flow rate, temperature and/or composition of the product gas to be maintained within acceptable ranges.

In one embodiment of the present invention, the process further comprises the step of pre-heating the coal prior to adding to the gasification reaction vessel 14.

In one embodiment, the gasification process according to the present invention employs the use of heated air or other oxidant from the gas-to-air heat exchanger 48 to heat the gasification reaction vessel 14 to a temperature appropriate for gasifying coal. In this embodiment, which is typically used at the start-up phase of the system 10, air is fed into the system, whereby it is heated by plasma heat to provide a hot start-up gas that then enters the gas-air heat exchanger 48 to generate heated air. The heated air is transferred to the heated air inlet means to heat up the gasification reaction vessel 14, such that the entire process can run without the use of fossil fuels.

The invention will now be described with reference to a specific example. It will be understood that the following example is intended to describe an embodiment of the invention and is not intended to limit the invention in any way.

EXAMPLE

In general, the system of the present invention is used by feeding the coal along with the heat from a source such as a plasma heat source 15, heated air, or any other heat source as may be appropriate, into a gasification reaction vessel 14 where the feedstock is subjected to sufficient heat to allow the gasification reaction to take place.

Heating of the coal results in removal of any residual moisture and volatilization of any volatile components, thereby providing a partially oxidized char product. Further heating of the partially oxidized char product completely converts the char to its gaseous constituents, leaving an ash by-product, which can then be further heated and converted to slag.

Extra oxygen may be injected into the gasification reaction vessel to initiate or to increase the exothermic reactions that produce carbon monoxide, carbon dioxide and carbon particles. The exothermic reactions along with the heat optionally provided by the heated process air increase the processing temperature in the gasification reaction vessel 14.

In one embodiment, the processing temperature is between about 1000 °C to about 1300 °C, although lower and higher temperatures are also contemplated. In one embodiment of the present invention, the process employs an average gasification temperature within the reaction vessel is about 1100 °C +/- 100 °C.

Reformation

The offgas that is formed in the gasification reaction vessel 14 is further heated with a plasma heat source 15 and optionally treated with steam. These reactions are mainly endothermic. In one embodiment of the present invention, the temperature is maintained in a range that is high enough to keep the reactions at an appropriate level to ensure complete conversion to the specified gas product, while minimizing pollution production. In one embodiment, the temperature range is from about 900 °C to about 1300 °C. Appropriate temperature ranges can readily be determined by the skilled worker.

The steam that is added in the reformation step acts to ensure formation of a gas product having a specified composition, while also reducing the exit temperature of the gas. In one embodiment, the exit temperature of the product gas is reduced to between about 900 °C and about 1200 °C. In another embodiment, the product gas exit temperature is reduced to an average temperature of about 1000 °C +/- 100 °C.

In one exemplary embodiment, the amount of coal, oxygen, steam and power to the plasma heat sources 15 may be determined on the basis of monitoring the flow rate of the exit synthesis gas, the exit temperature of the exit synthesis gas and the composition of the exit gas.

With specific reference to Figures 15 and 16, the numerical value of the flow rate of carbon monoxide and carbon dioxide in the exit gases via lines 100 and 102, is

inputted into a first processor (illustrated by logic box 30) along with the numerical value of the feed rate of coal in line 104 (e.g. obtained via regulating means 206-1). The first processor 30 estimates the amount of carbon in the gasification reaction vessel 14 and adjusts the coal feed rate accordingly.

Output from first processor 30, which provides a measure of the numerical value of the per cent carbon monoxide and the per cent carbon dioxide is inputted via line 106 to a second processor (illustrated by logic box 32) along with the numerical value of the per cent hydrogen via line 108, and the numerical values of steam (e.g. via regulating means 206-2) and oxygen (e.g. via regulating means 206-3) via line 110. The second processor 32 estimates new oxygen and steam inputs to achieve the specified gas composition.

Output from the second processor 32 are inputted into a third processor 34 via line 112 along with an input representative of the numerical value of the exit gas temperature via line 114. The third processor 34 computes new plasma heat source power (e.g. plasma torch) that outputs as power output (e.g. sent to regulating means 206-4) via line 116.

Melting of By-Product Ash

In one embodiment of the invention, the solid ash by-product of the char combustion step is further optionally processed by melting with a second plasma heat source 44. Enough time is allowed when the particles are entrained in the slag pool to ensure that all volatiles and carbon are completely removed. As would be appreciated by a worker skilled in the art, the residence time is a function of the particle size. The heat produced by the second plasma heat source 44 homogenizes the slag and allows it to be extracted while hot. The plasma heat source 44 heats the slag to a temperature between about 1100 °C and about 1600 °C. In one embodiment, to a temperature is between about 1400 °C and about 1650 °C. This manipulation of the temperature profiles can help to avoid wasting heat and later water to quench the slag in the bottom of the gasification reaction vessel 14.

Although the invention has been described with reference to certain specific embodiments, various modifications thereof will be apparent to those skilled in the art without departing from the spirit and scope of the invention as outlined in the claims appended hereto.

The following examples have been provided to compare the gasification of two low rank coals, lignite and sub-bituminous coal (see Table 1), to produce syngas with a heating value suitable for Integrated Gasification Combined Cycle (IGCC) power generation.

The following two examples, are provided to demonstrate the operational parameters required to provide a syngas suitable for use in an IGCC, wherein the combined cycle comprises of one gas turbine (42MW) and one steam turbine. In the present example, GE MS6001B Combined Cycle is selected as the targeted model for both cases: the net plant power output is about 64MW. According to the present examples, the overall efficiency of the combined cycle could reach above 45%, much higher than traditional coal-fired power plant (30~33%).

The gasification reaction vessel can either be based on an entrained flow or a fluidized bed type reactor. An air separation unit (ASU) will supply 95% oxygen as the primary oxidant. Solid residues will be transformed to slag by a plasma torch at high temperature. The raw gas coming out from the converter is cooled and scrubbed before further gas cleaning processes, such as fine particulates and sulfur removal. The clean and conditioned syngas will be fed into gas turbine and combusted to generate electricity. The high temperature exhausting flue gas is introduced to a heat recovery steam generator (HRSG), which supplies steam for steam turbine, boosting the capacity of the electricity generation.

Table 1. Lignite and Sub-bituminous coal composition

Coal type	C	H	O	N	S	Moisture	HHV Btu/lb
Lignite	40.6%	6.9%	45.1%	0.6%	0.9%	36%	7000
Sub-bituminous	50.5%	6.2%	35.5%	0.7%	0.3%	25%	8560

Note: C,H,O... fraction is in term of weight.

Lignite as feedstock

The gasification reaction vessel operates at temperature ranging from 1000 °C to 1100 °C, under a pressure ranging from 2 atm to 10 atm. The coal input rate is controlled at 1309 T/day and pre-dried down to 10% moisture. The oxidant employed is 95% purity oxygen, provided at an oxidant input rate of about 205 SCFM (463 T/day). The syngas, after cooling and cleaning, consists of 35.6% H₂ and 31.4% CO with heating value of 9.1 MJ/m³. The volume flow rate of the dry clean syngas is about 47,323 m³/hr. The cold gas efficiency, taking into account how much energy is transferred to syngas from solid fuels, is about 85%.

Sub-bituminous coal as feedstock

The gasification reaction vessel operates at an average temperature of 1100 °C, under a pressure ranging from 2 atm to 10 atm. The coal input rate is controlled at 617 T/day and pre-dried down to 10% moisture. The oxidant employed is 95% purity oxygen, provided at an input rate of about 85 SCFM (127 T/day). The syngas, after cooling and cleaning, consists of 45.0% H₂ and 30.5% CO with heating value of 10.2 MJ/m³. The volume flow rate of the dry syngas is about 51,400 m³/hr. The cold gas efficiency of the gasification system is about 86%.

As indicated, a comparison of the gasification of sub-bituminous coal and lignite to produce a gas having a similar heating value, demonstrates that the gasification of lignite will consume more oxygen as oxidants and produce less syngas for the gas turbine; it means more lignite will be needed to generate the same amount of electricity than sub-bituminous coal. The cold gas efficiency of lignite as feedstock is also lower than that of sub-bituminous as expected. The present examples, however, indicate that the present gasification system can be used to convert low rank coal to a syngas having a heating value suitable for IGCC power generation.

The disclosure of all patents, publications, including published patent applications, and database entries referenced in this specification are specifically incorporated by reference in their entirety to the same extent as if each such individual patent,

publication, and database entry were specifically and individually indicated to be incorporated by reference.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A system for the conversion of coal to a gas of a specified composition, comprising:

a gasification reaction vessel comprising one or more processing zones, one or more plasma heat sources; one or more coal input means for adding the coal to the gasification reaction vessel at an adjustable coal feed rate, one or more process additive input means for adding process additives to the gasification reaction vessel at an adjustable process additive feed rate, and one or more outlets for the output gas,

a solid residue handling subsystem;

a gas quality conditioning subsystem;

an integrated control system comprising:

system monitoring means for measuring one or more system parameters to generate data,

computing means for collecting and analyzing the data generated by the system monitoring means, and

output means to send appropriate signals to effect change in one or more system regulators located throughout the system,

wherein the control system monitors the one or more system parameters and sends signals to the appropriate system regulators to effect change in the one or more system regulators and thereby produce a product gas of a specified composition.

2. The system according to claim 1, further comprising a heat recovery subsystem, wherein the heat recovery subsystem comprises one or more gas-to-air heat exchangers, and means to transfer the product gases to the one or more gas-to-air heat exchangers, wherein the transfer means is in fluid communication with the one or more output gas outlets.

3. The system according to claim 2, wherein the heat recovery subsystem further comprises one or more heat recovery steam generators, and means to transfer the product gases to the one or more heat recovery steam generators.

4. The system according to claim 1 or 2, wherein the gas quality conditioning subsystem comprises one or more of a particulate matter removal means, an acid gas removal means, a heavy metals removal means, and a means for adjusting the humidity and temperature of the gas as it passes through the gas quality conditioning subsystem.

5. The system according to any one of claims 1 to 4, further comprising a product gas regulating subsystem.

6. The system according to claim 5, wherein the product gas regulating subsystem is a homogenization tank.

7. The system according to any one of claims 1 to 6, wherein the process additive input means is one or more steam inlets, one or more oxidant inlets or both.

8. The system according to claim 7, wherein the oxidant is air, oxygen or oxygen-enriched air.

9. The system according to any one of claims 1 to 8, wherein the solid residue handling subsystem comprises a solid residue conditioning chamber, a plasma heating means, and a slag output means.

10. A process for converting coal to a product gas having a specified composition, said process comprising the steps of:
passing coal into a gasification zone at a coal input rate;
passing a process additive into said gasification zone at an process additive input rate;
subjecting said coal to heating to provide an offgas and by-product ash;
passing the offgas to a reforming zone;
heating the offgas with a plasma heat source;
adding steam to said offgas at a steam input rate to convert the offgas to a synthesis gas.

11. The process according to claim 10, further comprising the steps of:

passing said by-product ash into a melting zone;

subjecting said by-product ash to heating by a slag conditioning plasma heat source to convert the by-product ash to slag and maintain the slag in a molten condition;

exhausting the molten slag from the melting zone, and

allowing said molten slag to cool to provide said vitreous slag.

12. The process according to claim 10 or 11, further comprising a corrective feedback procedure that comprises one or more of a step of monitoring the composition of the product gas, a step of monitoring the product gas flow and a step of monitoring the product gas temperature.

13. The process according to claim 12, wherein said corrective feedback procedure further comprises the step of adjusting one or more of the coal input rate, the oxygen input rate and the steam input rate to provide a specified product gas composition.

14. The process according to claim 12, wherein said corrective feedback procedure further comprises the step of adjusting one or more of the coal input rate, the oxygen input rate and the steam input rate to account for a measured change in the synthesis gas composition.

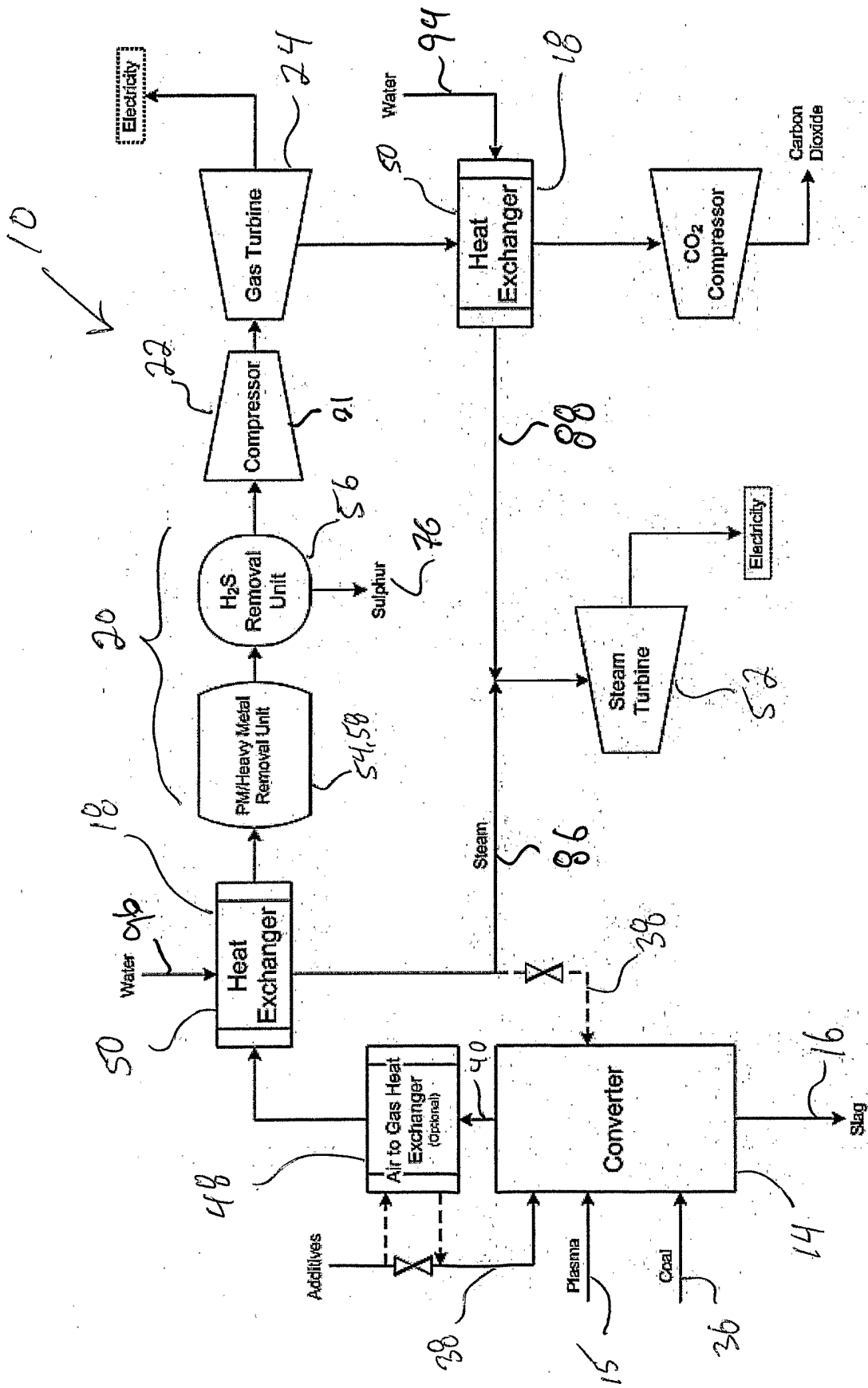


Figure 2

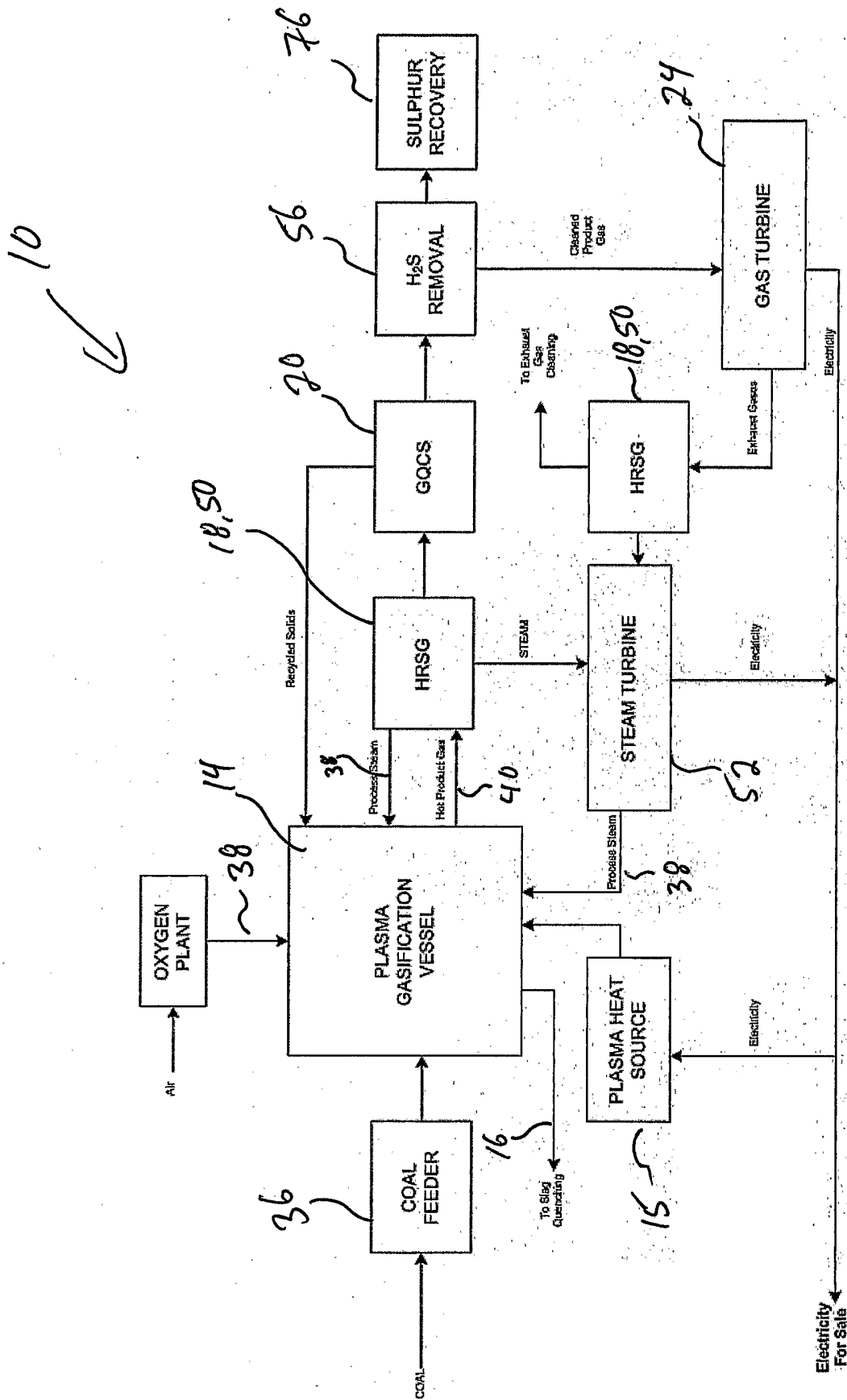


Figure 3

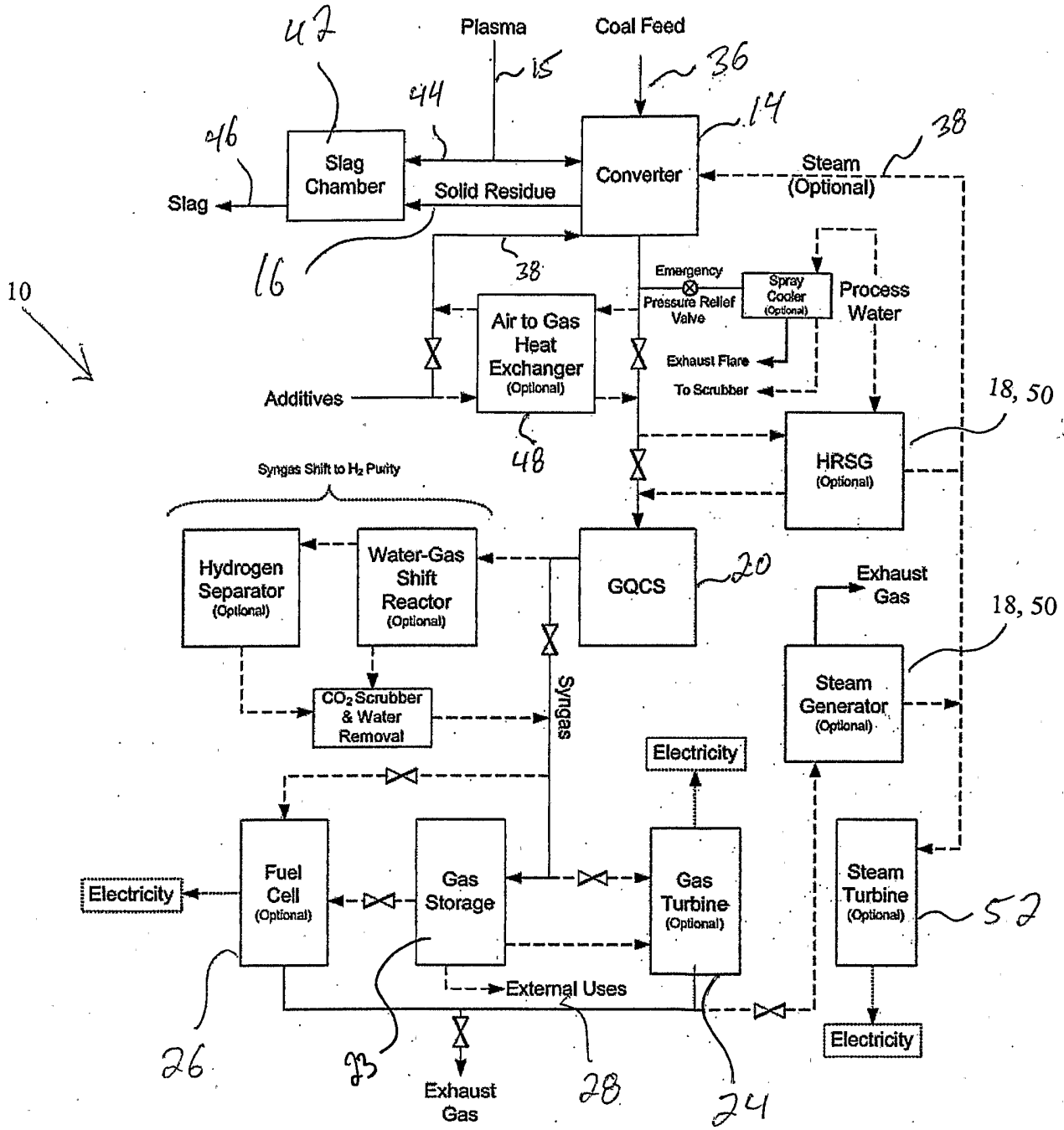


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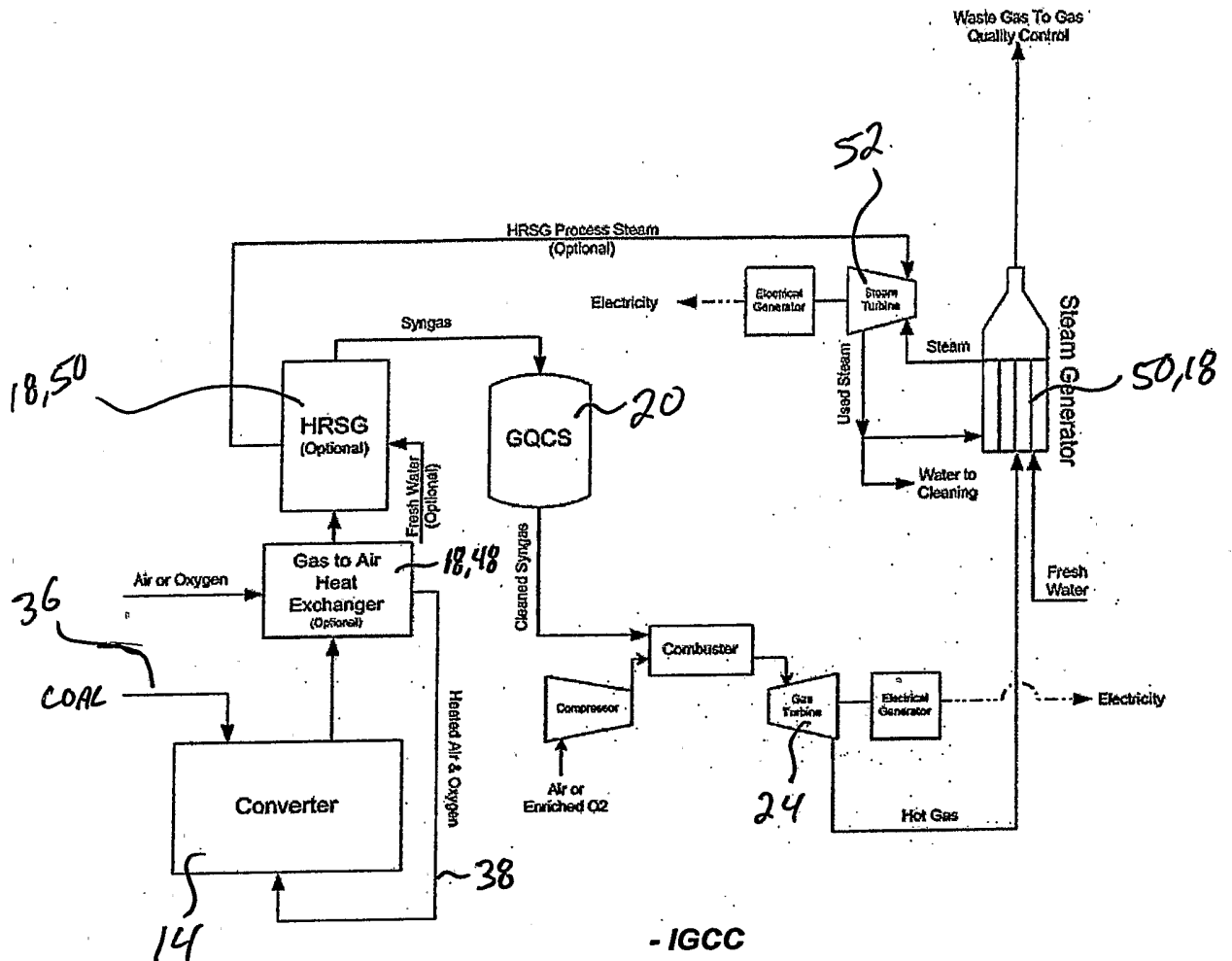


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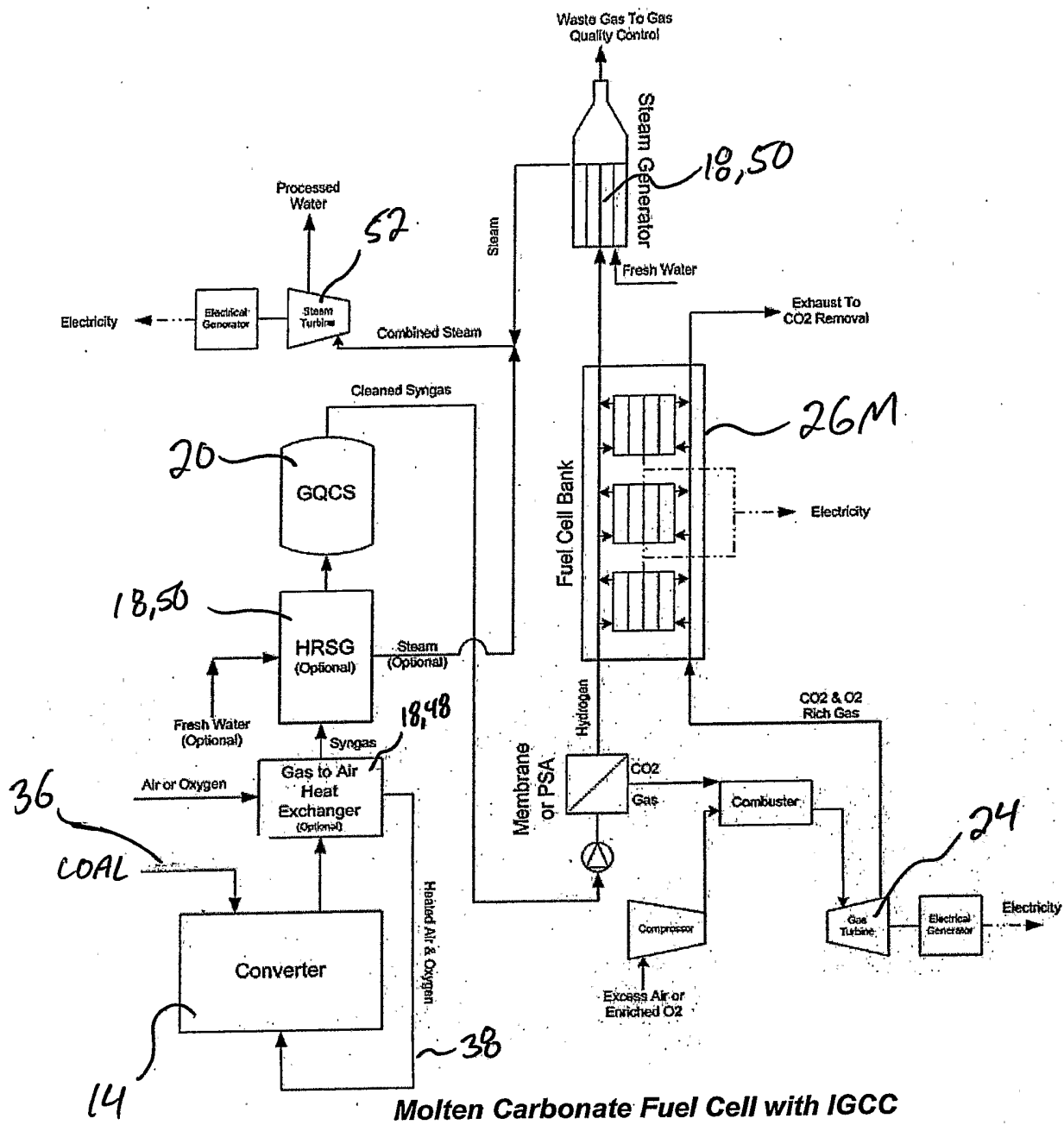
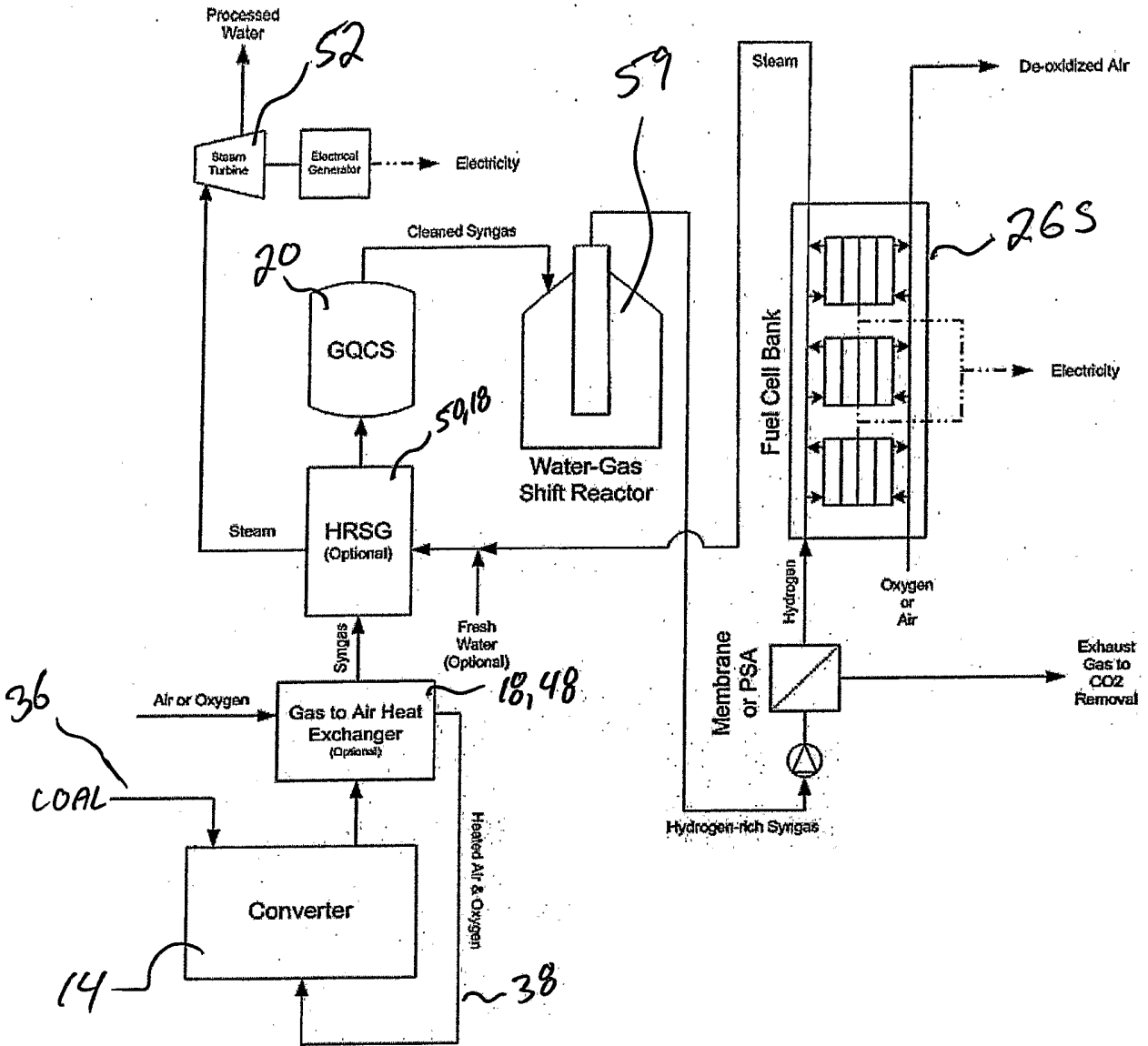
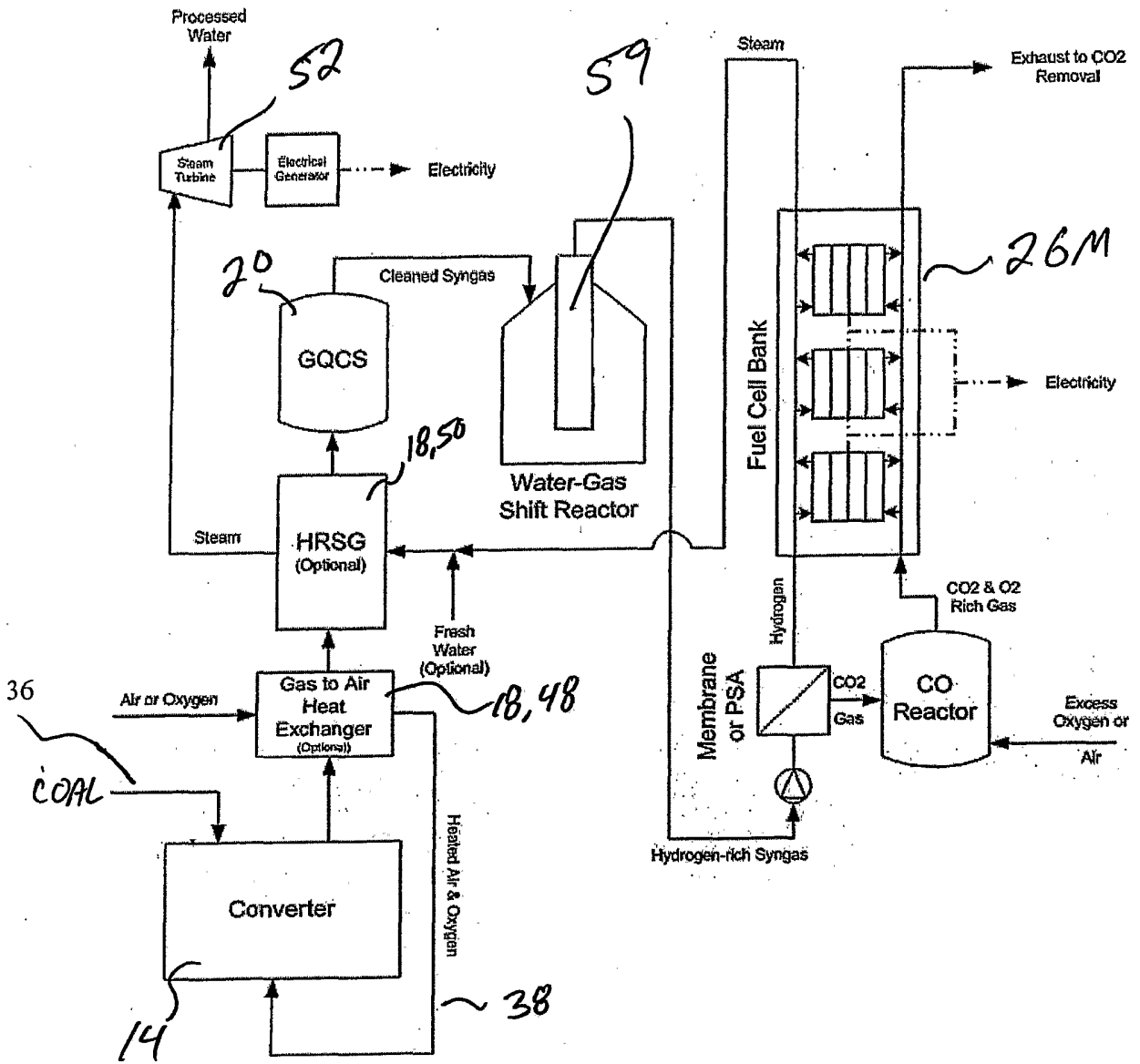


Figure 7



- Solid Oxide Fuel Cell with Steam Turbine c/w Water-Gas Shift Reactor

Figure 9



Molten Carbonate Fuel Cell with Steam Turbine c/w Water-Gas Shift Reactor

Figure 10

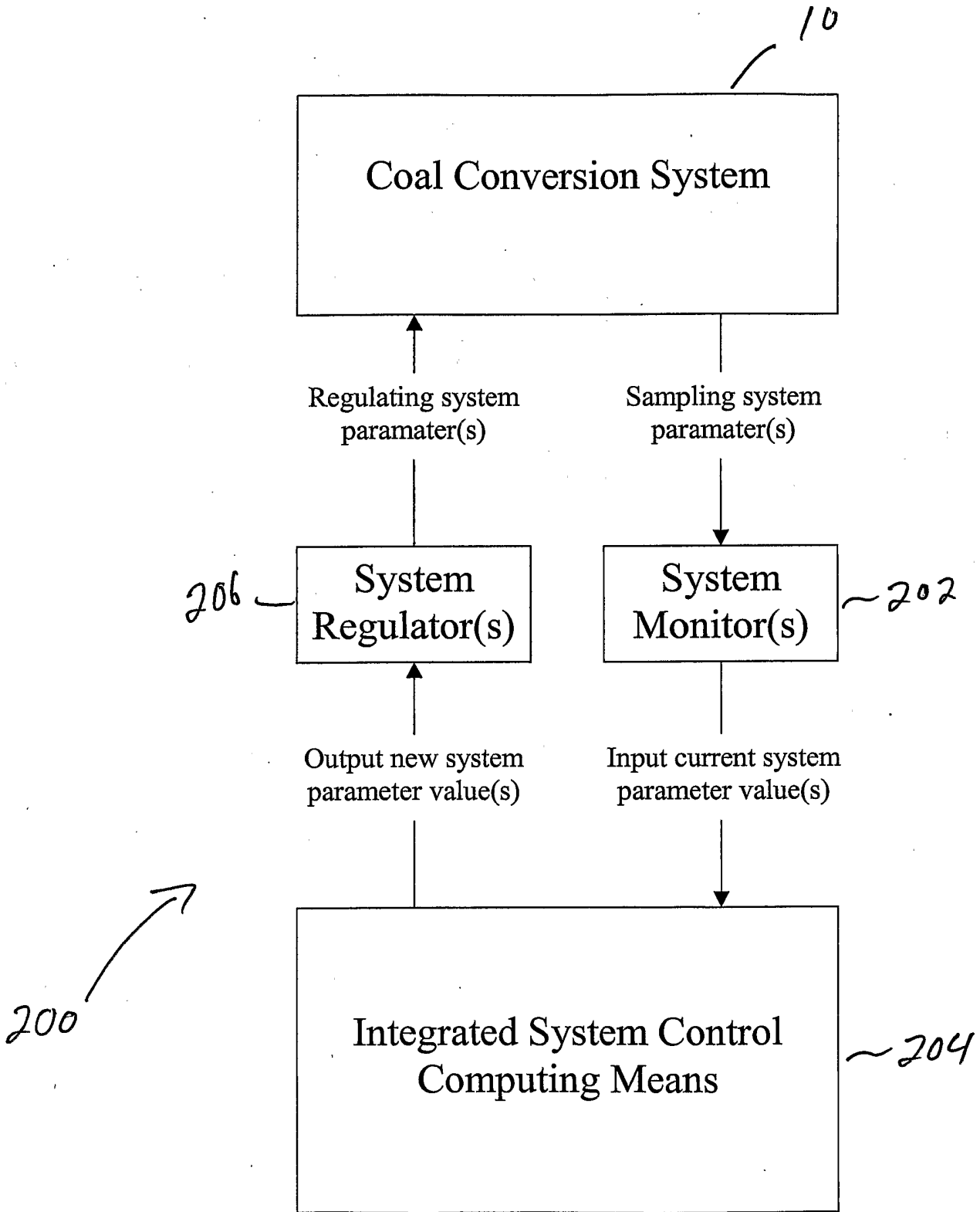
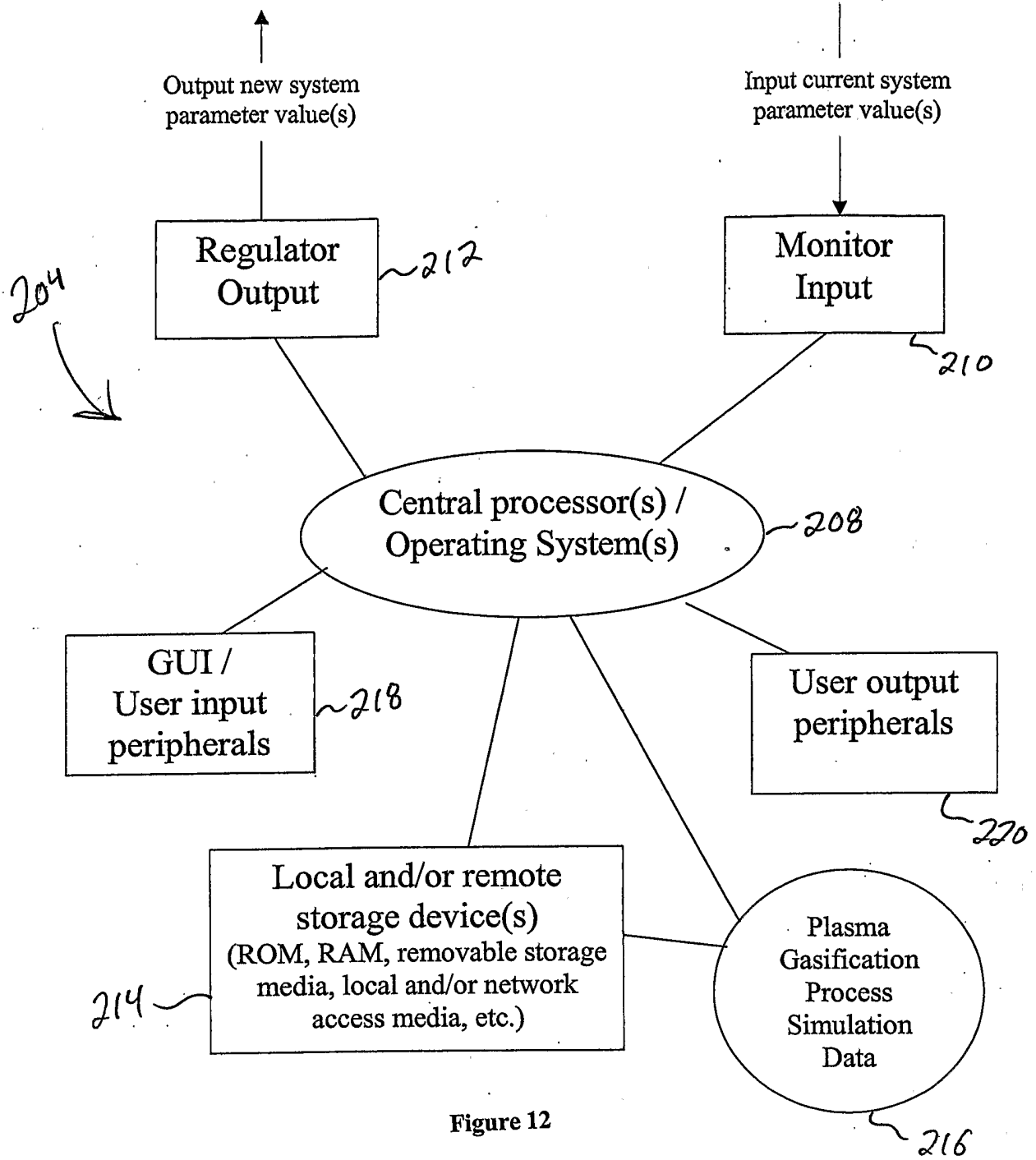


Figure 11



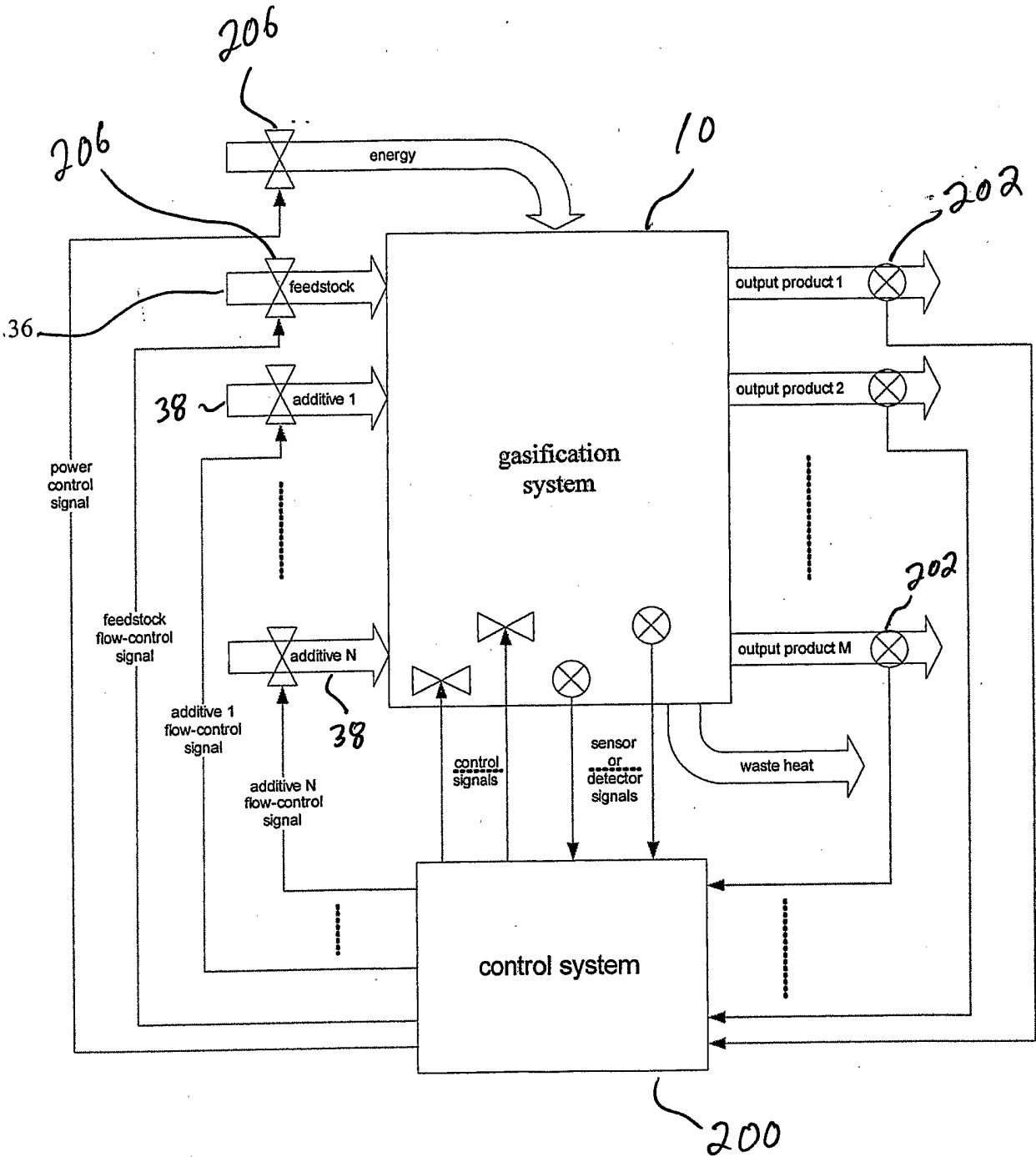


Figure 13

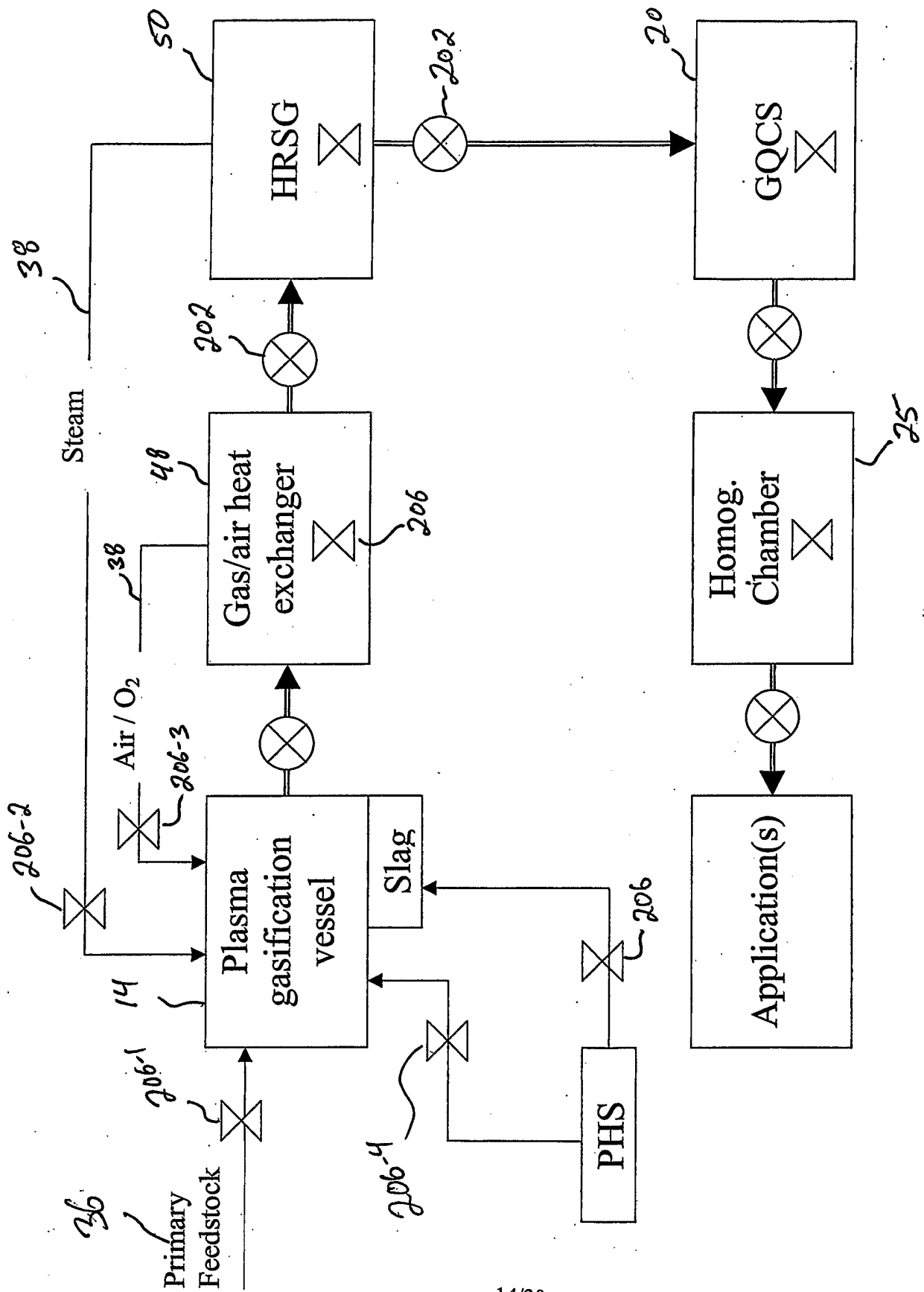


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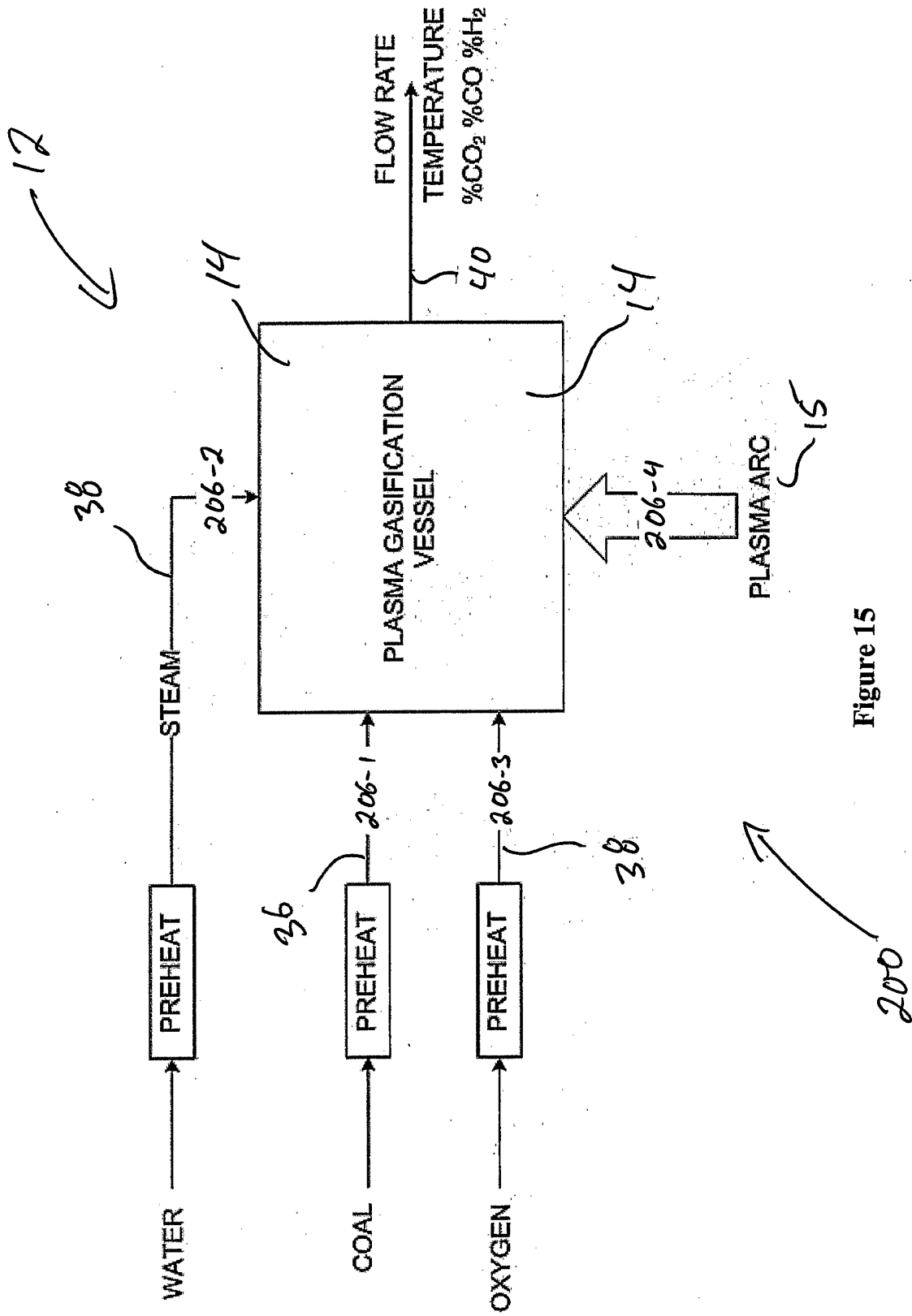


Figure 15

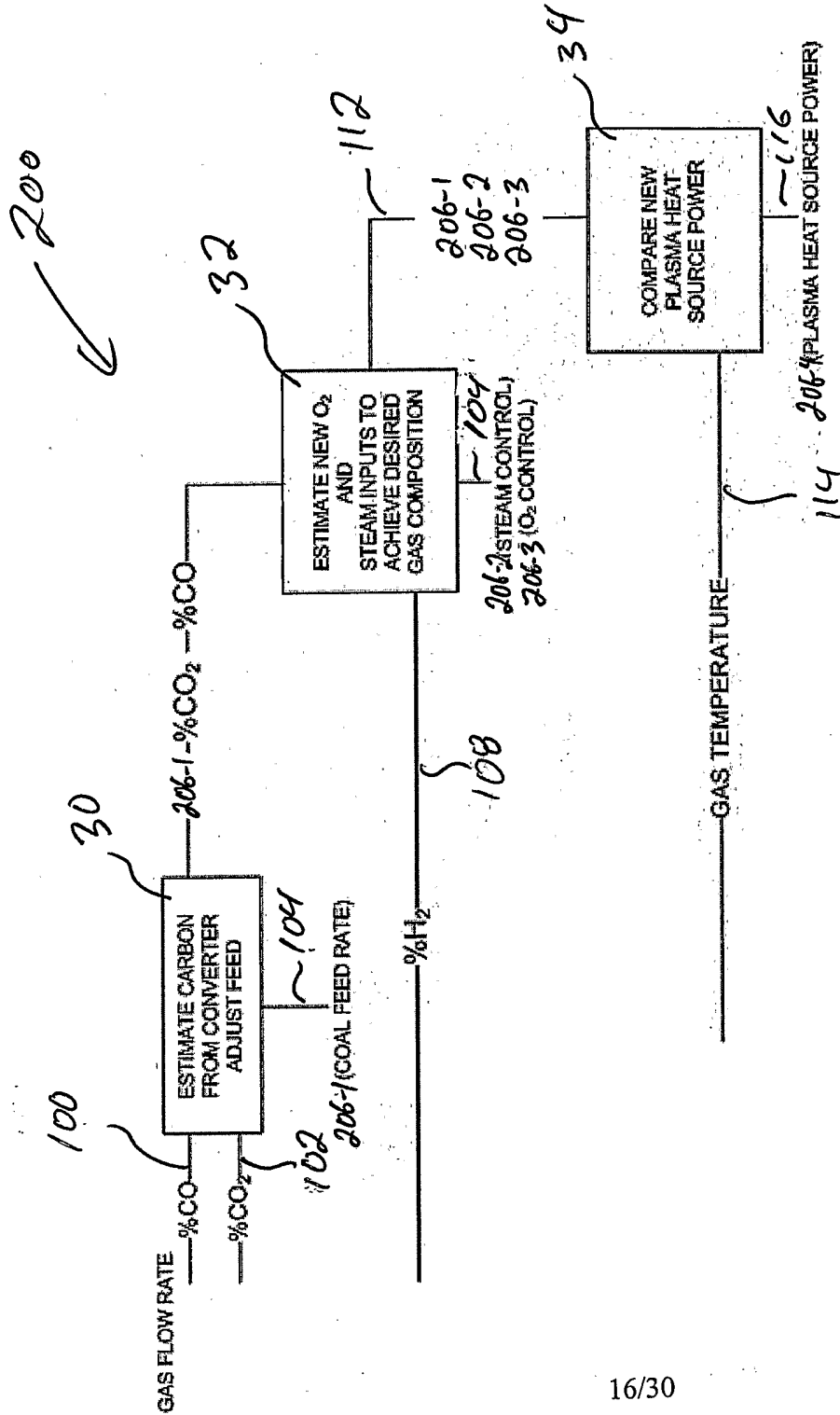


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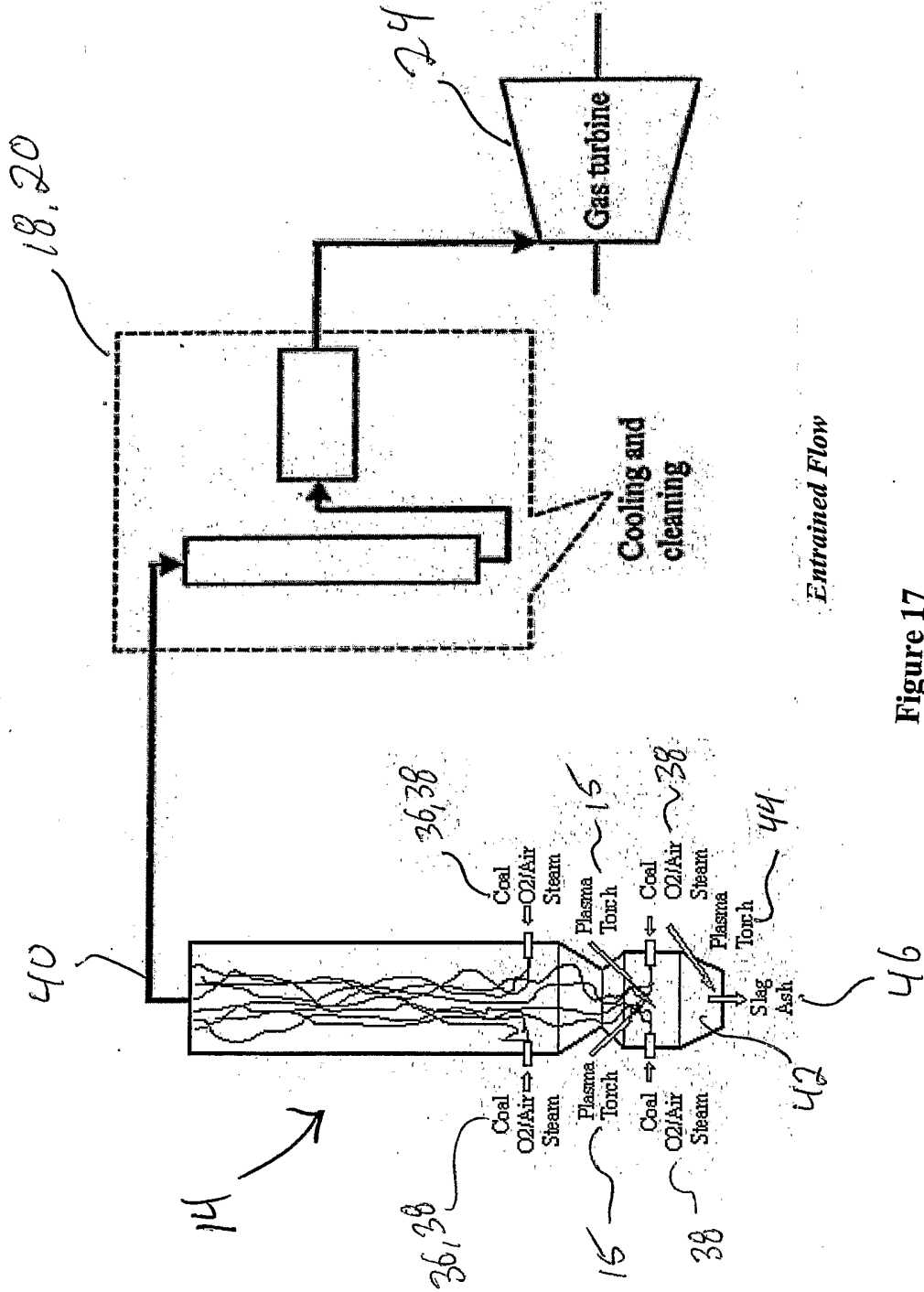


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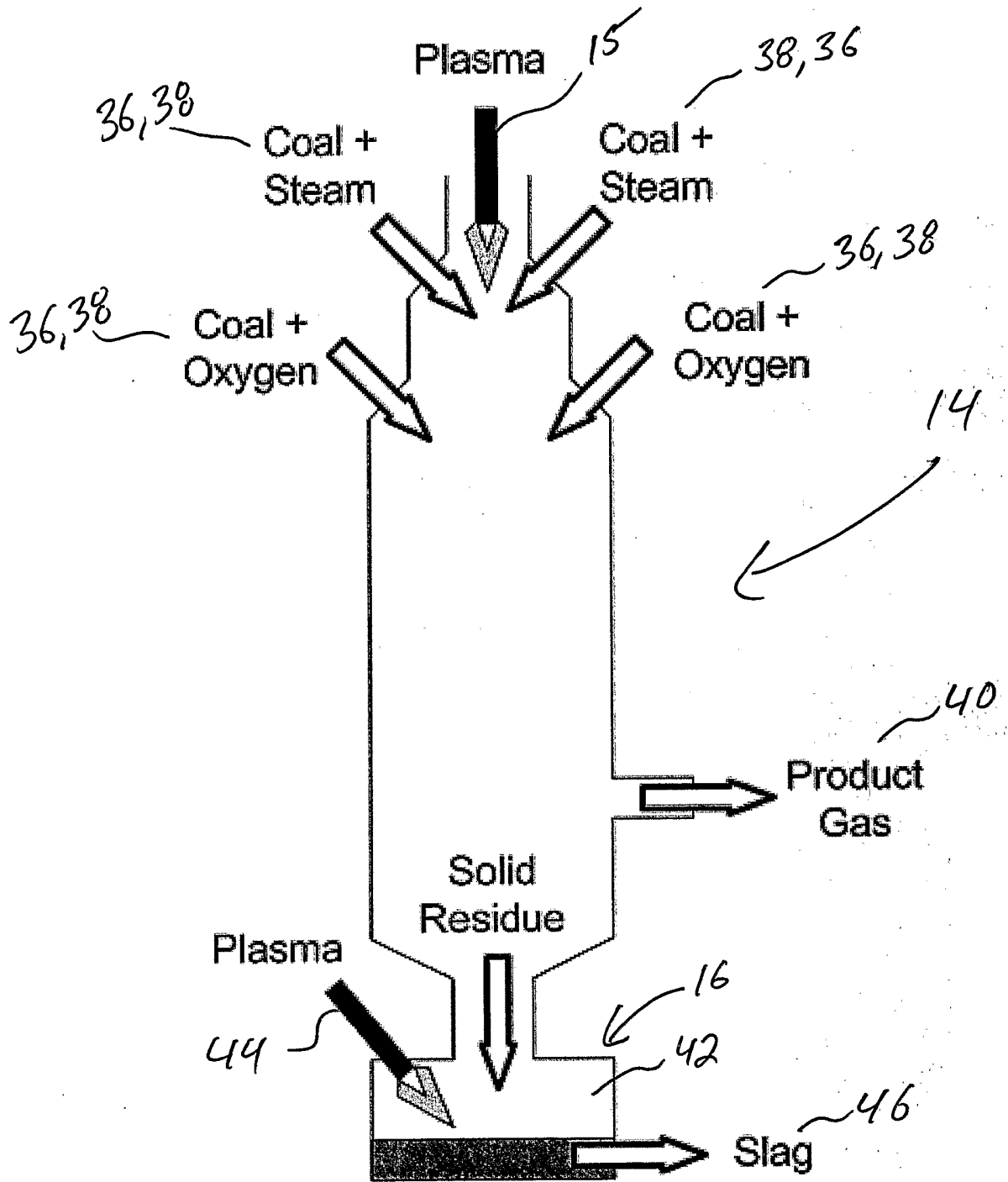


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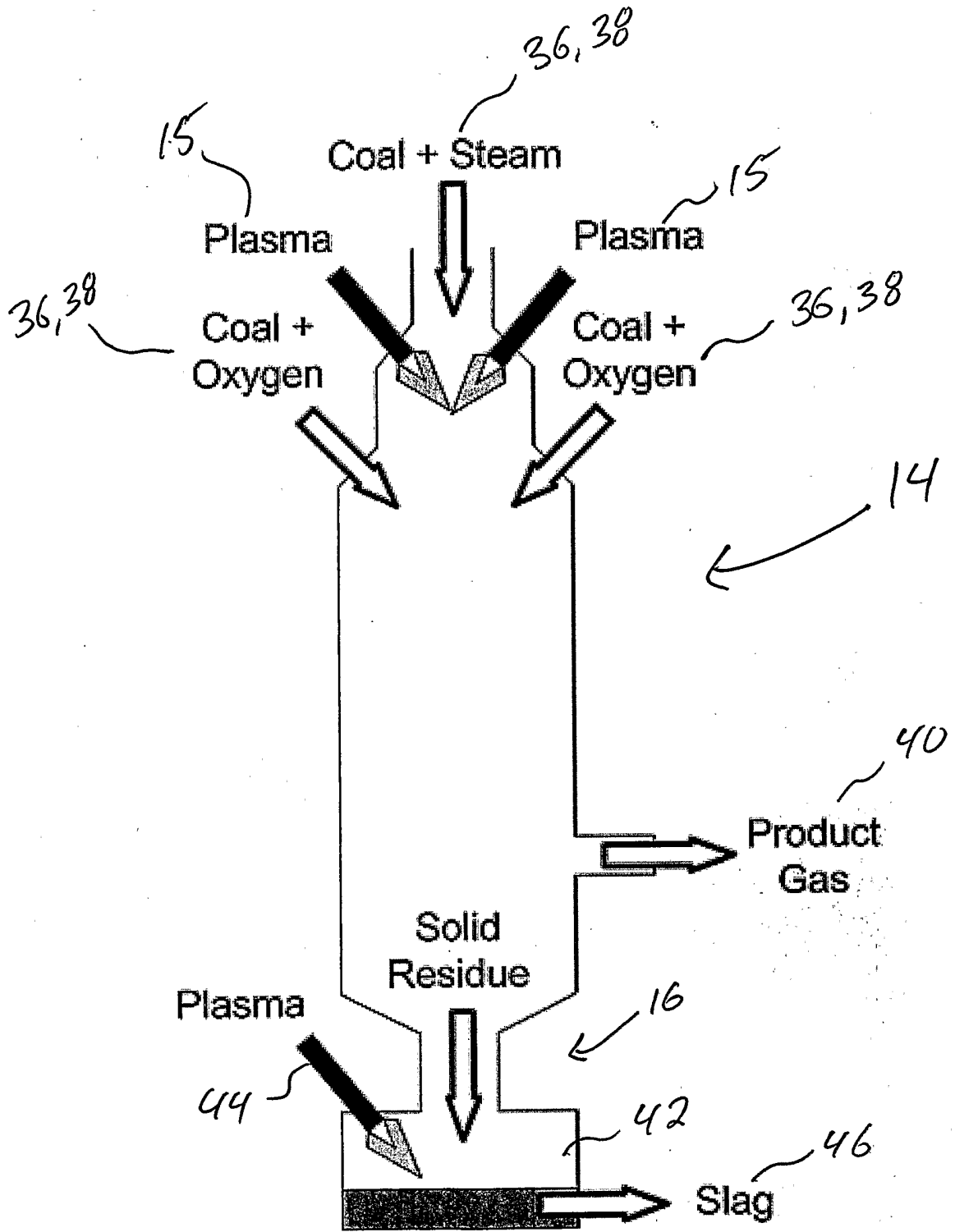


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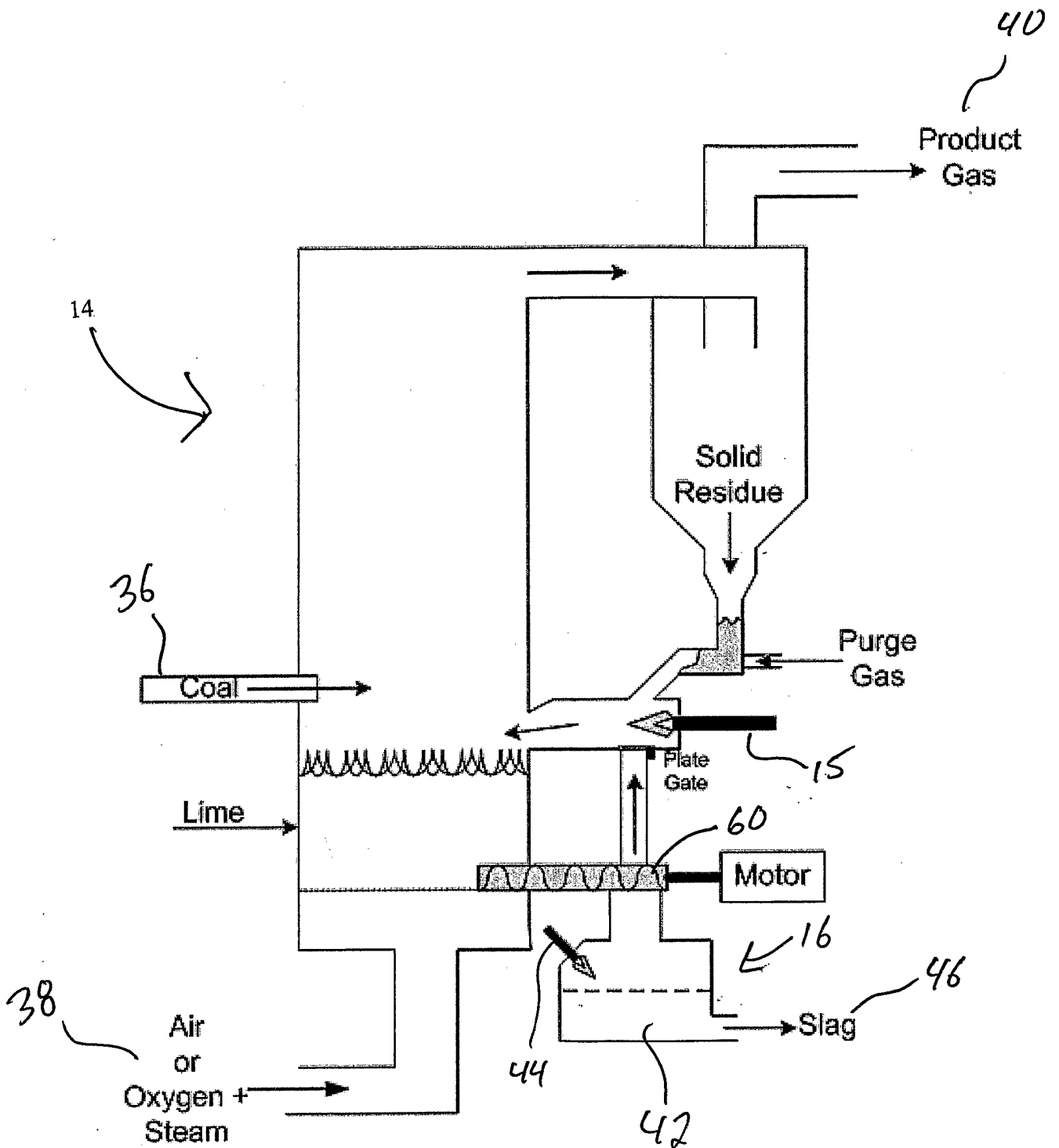


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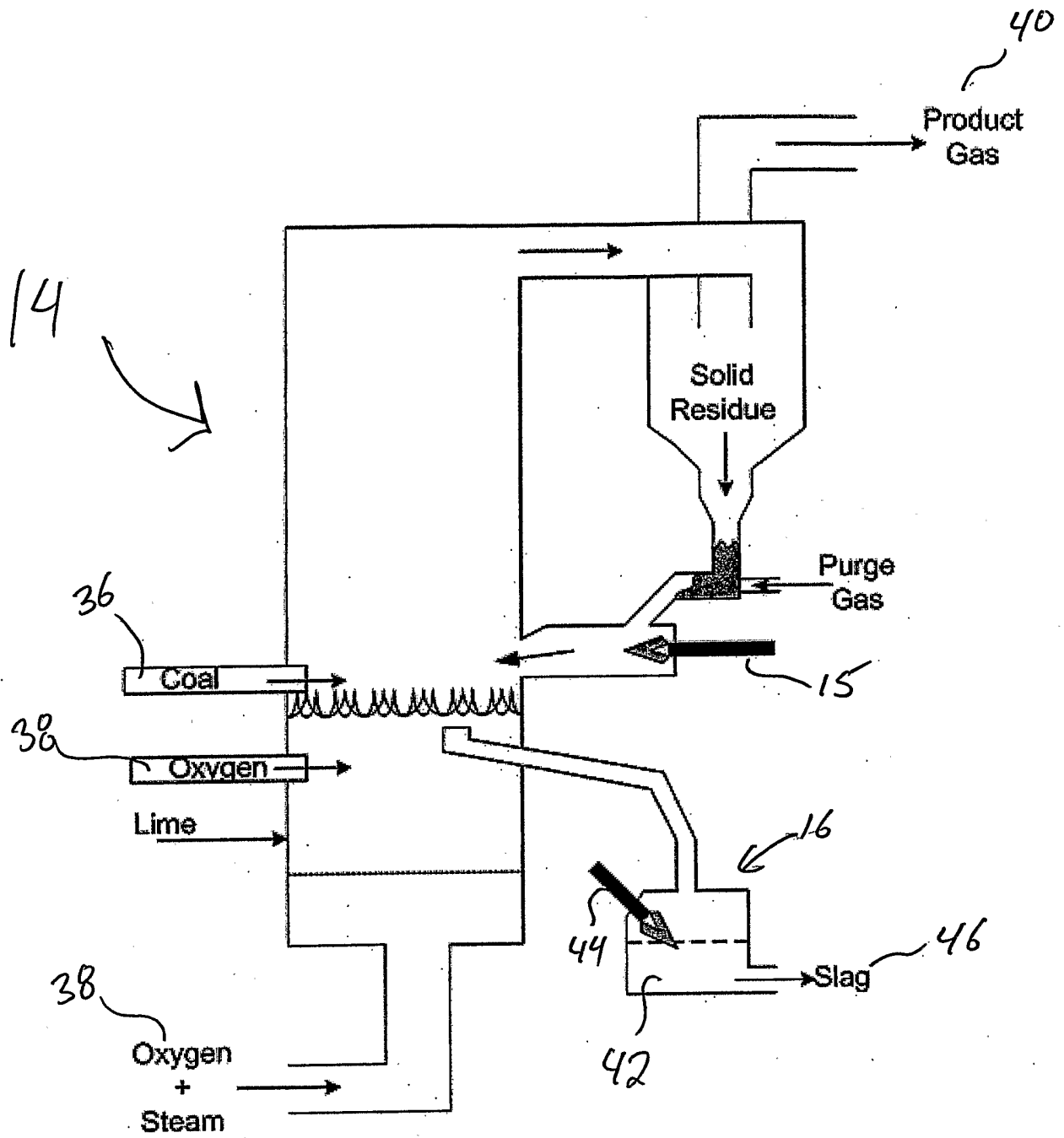


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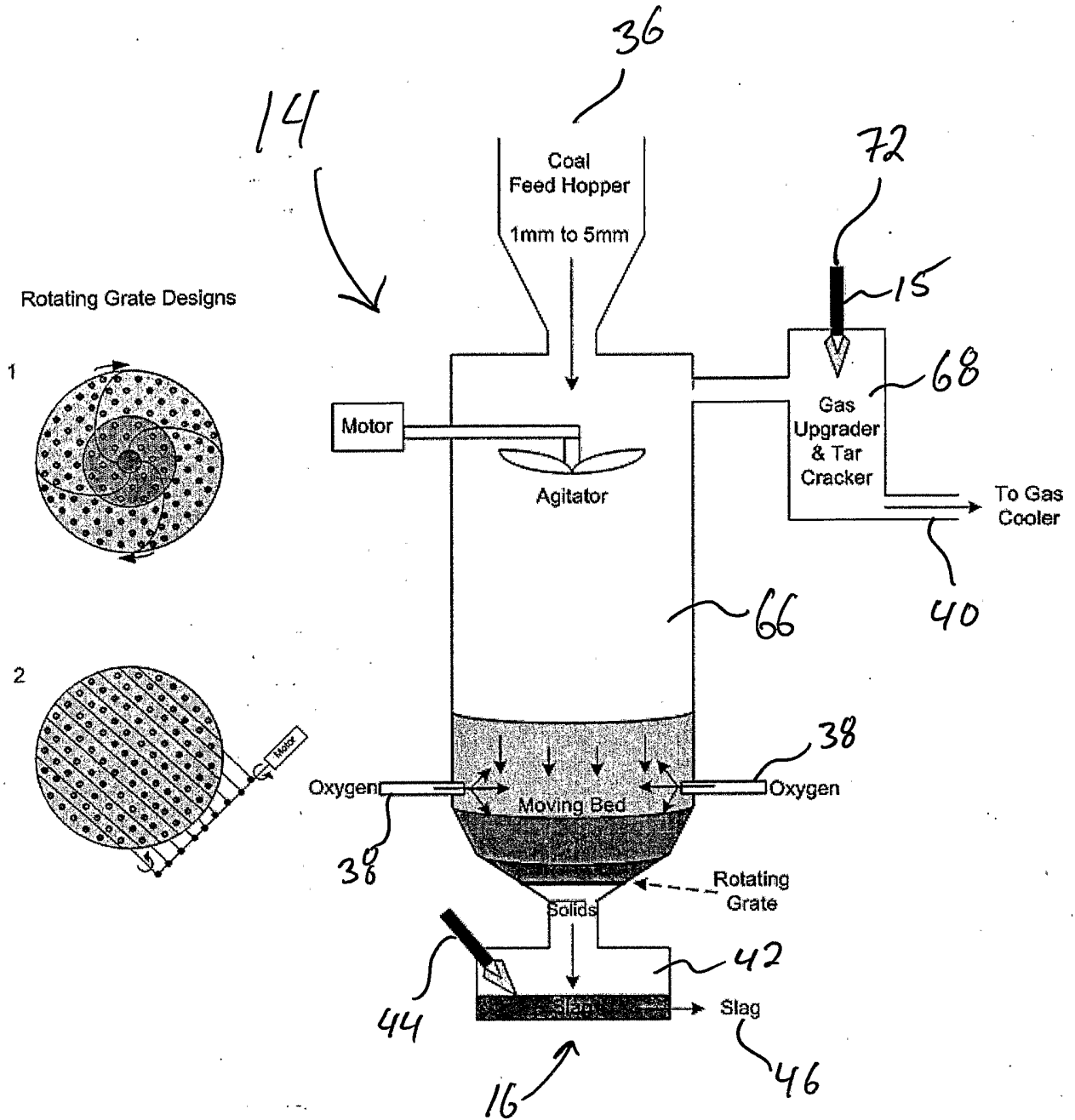
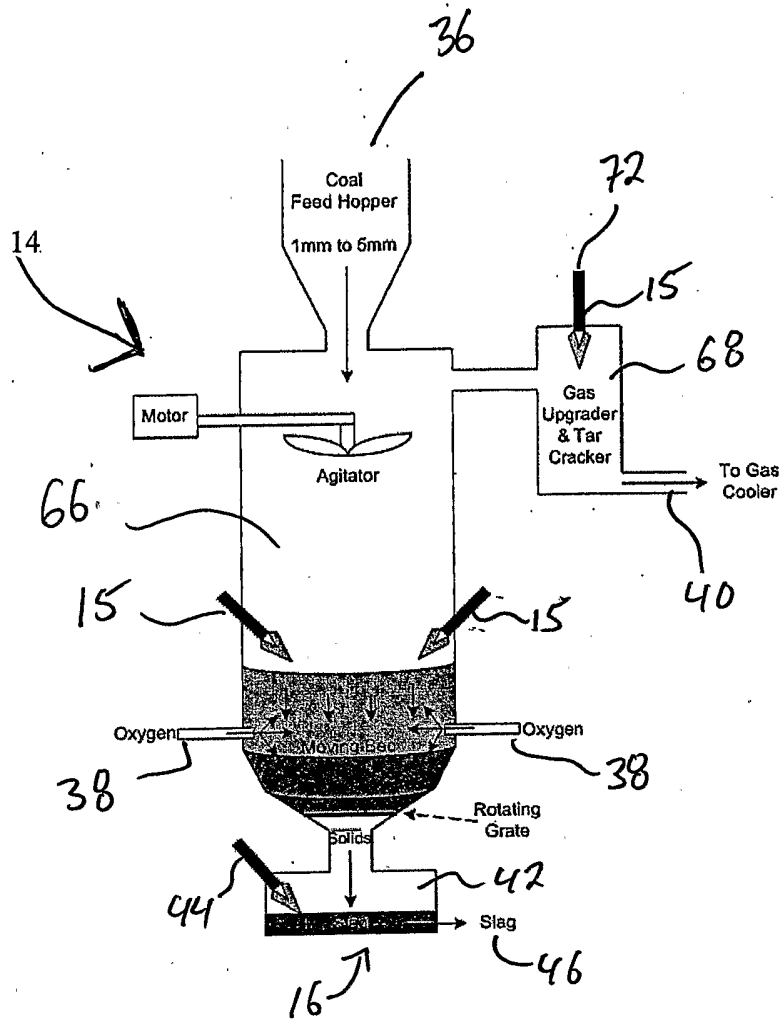


Figure 22



Rotating Grate Designs

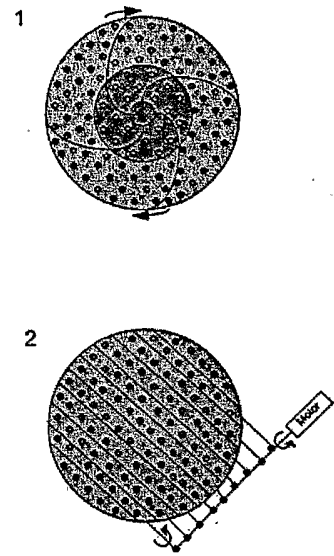


Figure 23

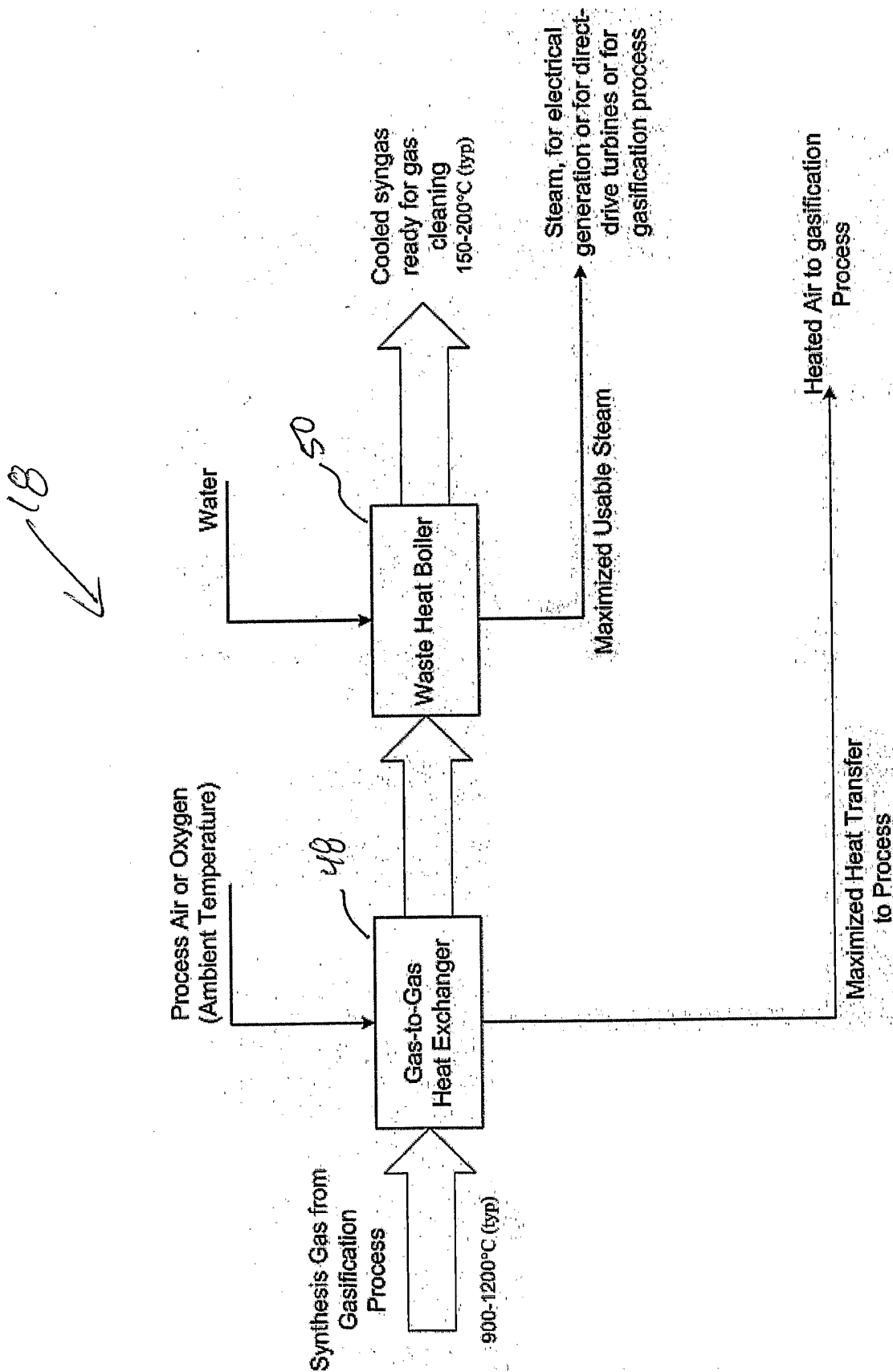


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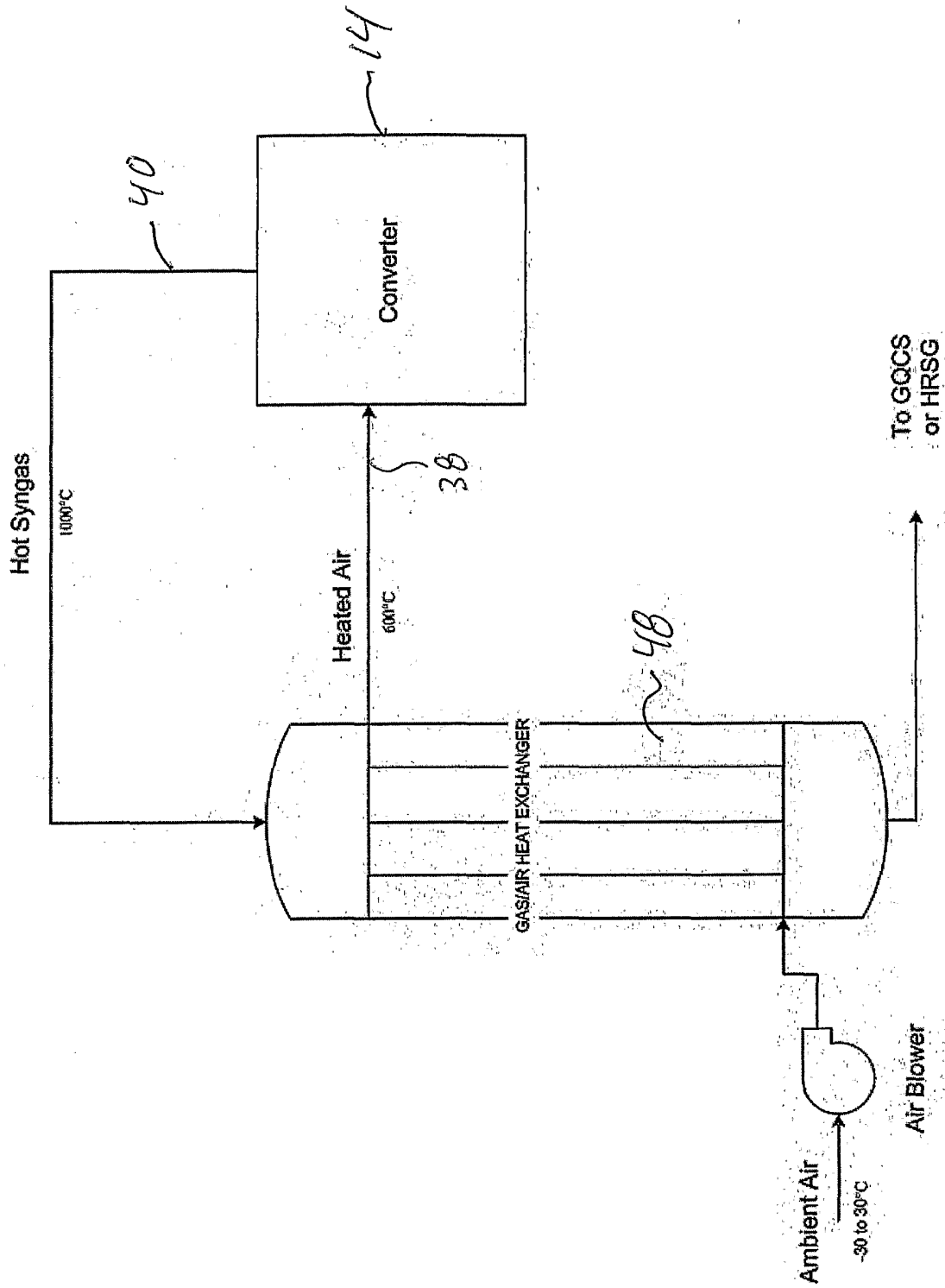


Figure 25

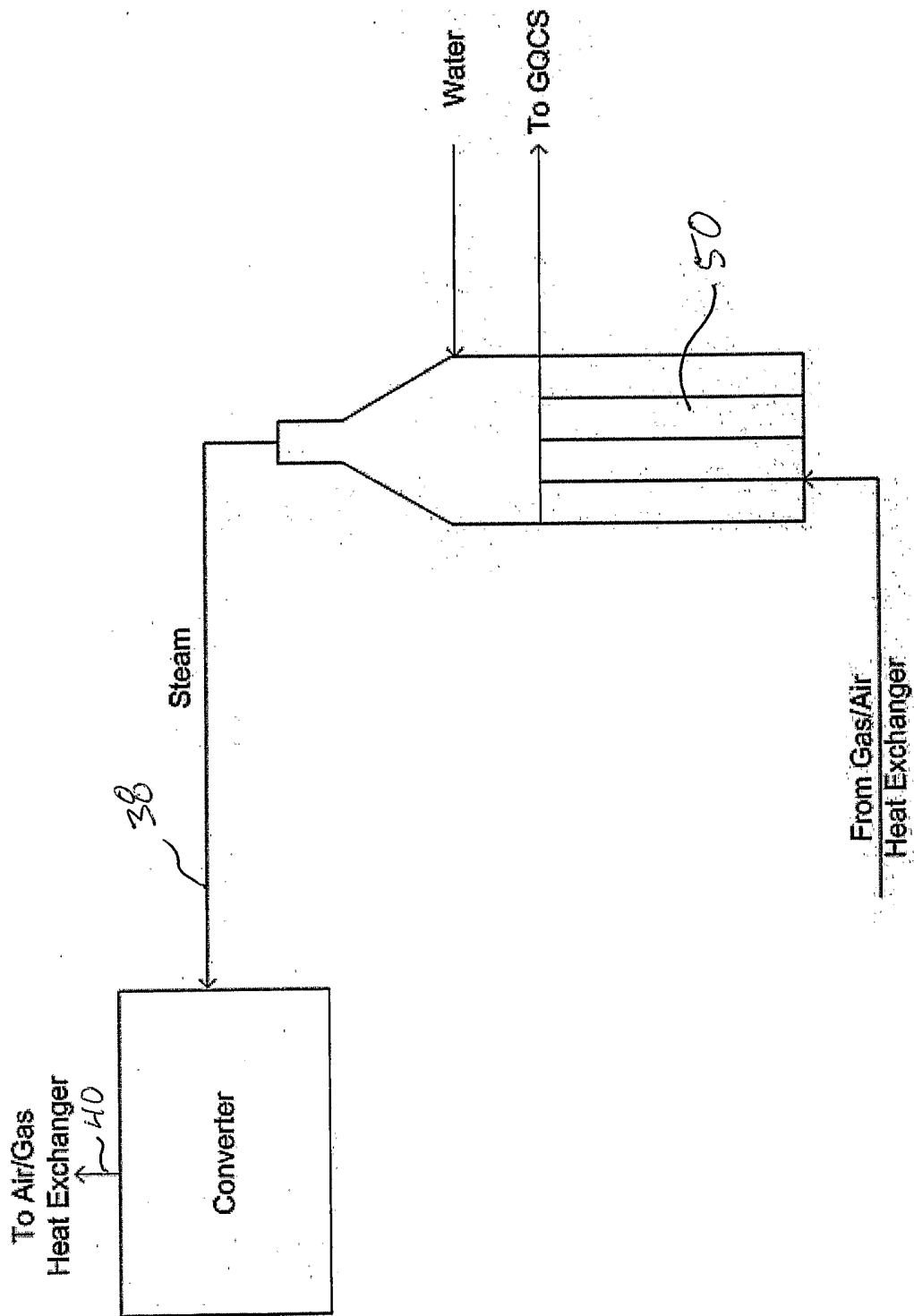


Figure 26

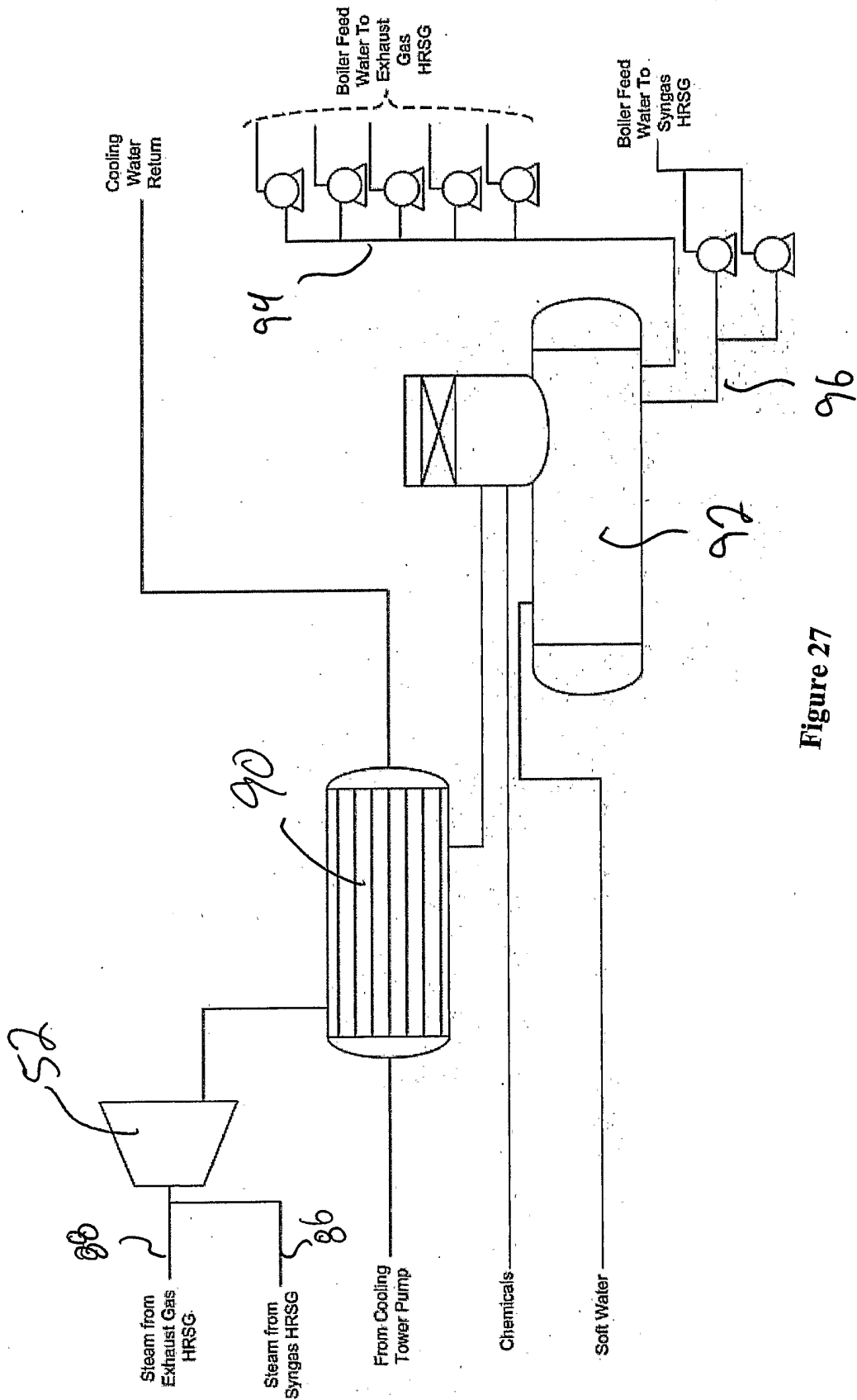


Figure 27

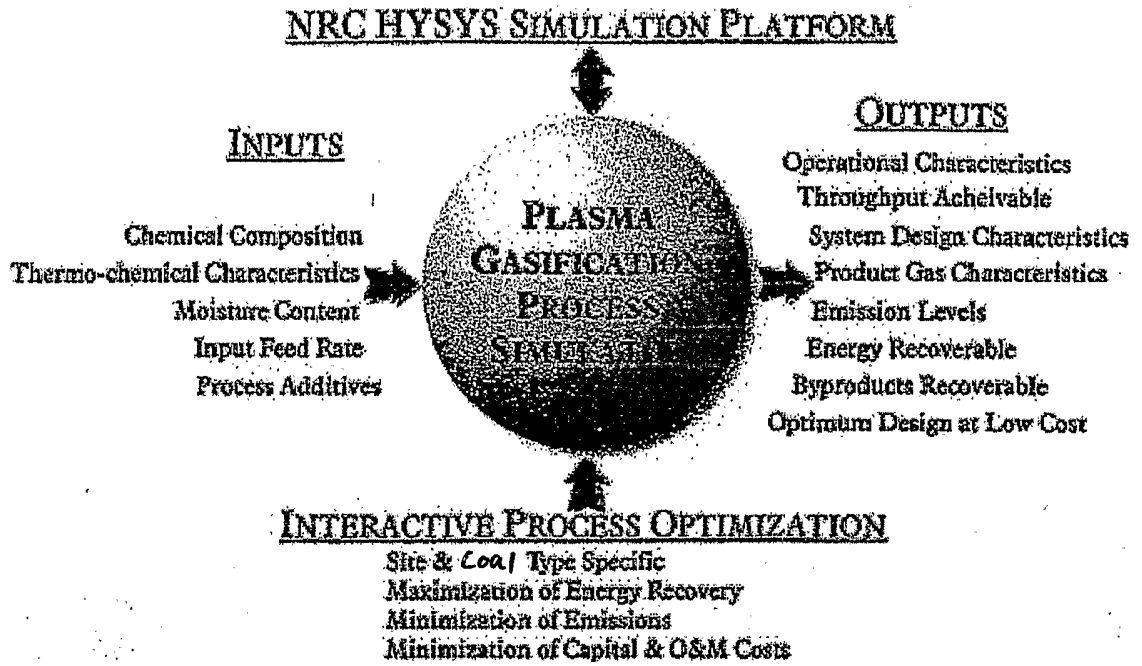


Figure 28

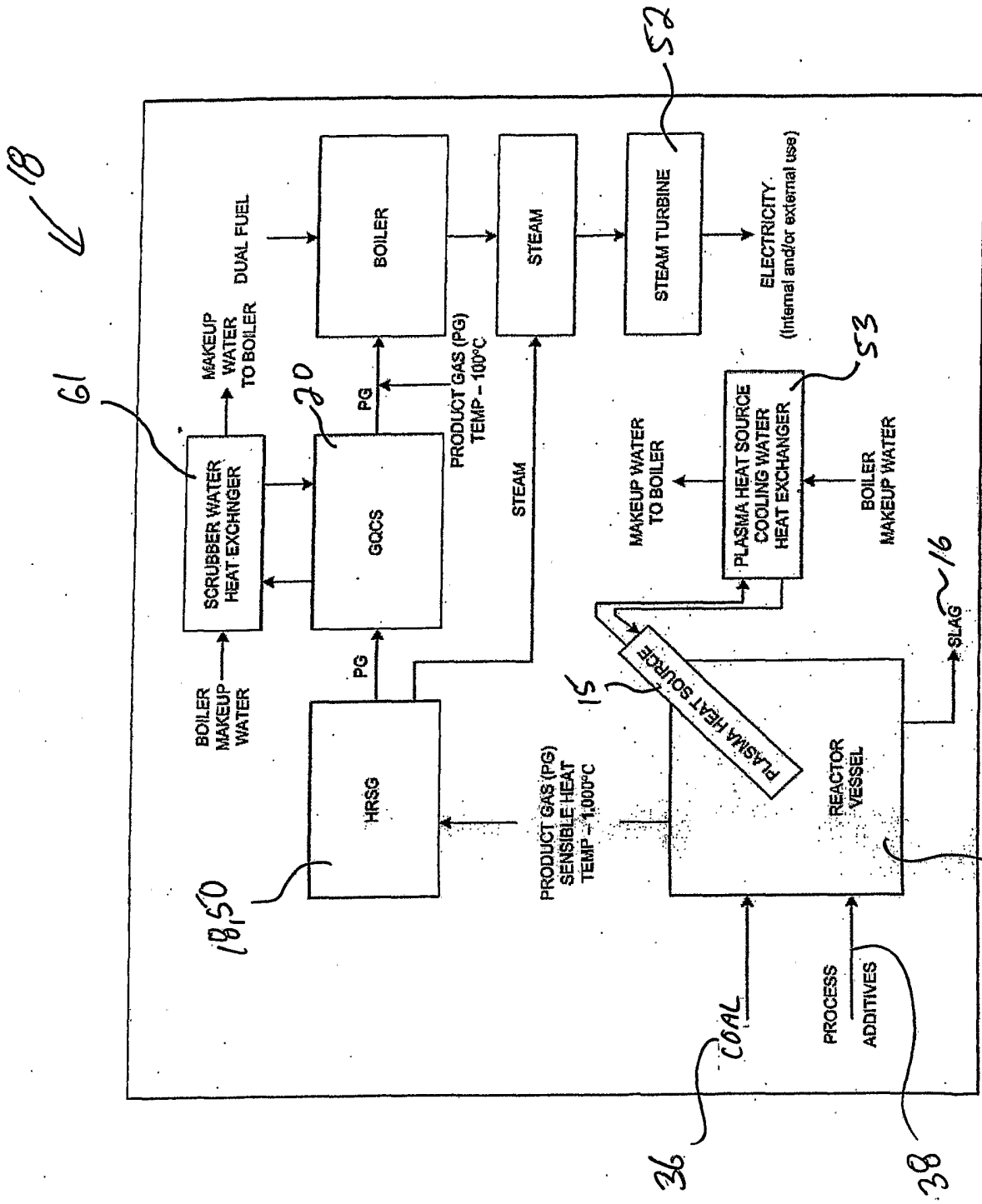


Figure 30

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2006/000882

<p>A. CLASSIFICATION OF SUBJECT MATTER IPC: <i>C10J 3/18</i> (2006.01) , <i>C10J 3/16</i> (2006.01) , <i>C10J 3/08</i> (2006.01) , <i>C10J 3/28</i> (2006.01) , <i>C10J 3/86</i> (2006.01) According to International Patent Classification (IPC) or to both national classification and IPC</p>														
<p>B. FIELDS SEARCHED</p> <p>Minimum documentation searched (classification system followed by classification symbols) IPC: C10J-3/* (2006.01)</p> <p>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched</p> <p>Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used) Canadian Patent Database, Delphion,, Espacenet, USPTO: IPCs + keywords; integrated control, control system, gasification, monitor, computing means</p>														
<p>C. DOCUMENTS CONSIDERED TO BE RELEVANT</p> <table border="1" style="width:100%; border-collapse: collapse;"> <thead> <tr> <th style="width:10%;">Category*</th> <th style="width:60%;">Citation of document, with indication, where appropriate, of the relevant passages</th> <th style="width:30%;">Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td align="center">Y</td> <td align="center">CA 2,343,035 (Texaco Development Corporation) 23 March 2003 (23-03-2000) [whole document]</td> <td align="center">1-8, 10, 12-14</td> </tr> <tr> <td align="center">Y</td> <td align="center">US 4,141,694 (Technology Application Services Corporation) 27 February 1979 (27-02-1979) [whole document]</td> <td align="center">1, 4-8, 10, 12-14</td> </tr> <tr> <td align="center">Y</td> <td align="center">US 4,272,255 (Mountain Fuel Resources, Inc.) 09 June 1981 (09-06-1981) [whole document]</td> <td align="center">1-8, 10, 12-14</td> </tr> </tbody> </table>			Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	Y	CA 2,343,035 (Texaco Development Corporation) 23 March 2003 (23-03-2000) [whole document]	1-8, 10, 12-14	Y	US 4,141,694 (Technology Application Services Corporation) 27 February 1979 (27-02-1979) [whole document]	1, 4-8, 10, 12-14	Y	US 4,272,255 (Mountain Fuel Resources, Inc.) 09 June 1981 (09-06-1981) [whole document]	1-8, 10, 12-14
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Y	US 4,272,255 (Mountain Fuel Resources, Inc.) 09 June 1981 (09-06-1981) [whole document]	1-8, 10, 12-14												
<p><input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.</p>														
<p>* Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>													
<p>Date of the actual completion of the international search 27 September 2006 (27-09-2006)</p>		<p>Date of mailing of the international search report 11 October 2006 (11-10-2006)</p>												
<p>Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001(819)953-2476</p>		<p>Authorized officer Malcolm Downey (819) 934-2329</p>												

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2006/000882

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